From *Cambridge Ancient History*, Volume 7, Part 1 (New York, 1984)

CHAPTER 9

HELLENISTIC SCIENCE: ITS APPLICATION IN PEACE AND WAR

9a HELLENISTIC SCIENCE

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INTRODUCTION

Although there are marked continuities between classical and Hellenistic science,[1] the conditions and circumstances in which scientific investigations were conducted, and to some extent the nature of those investigations themselves, were, in certain respects, changed in the Hellenistic world. Four points that concern the different strands of scientific research to varying degrees are (1) the greater inter-penetration of Greek and non-Greek ideas, (2) the increasing specialization of the sciences, (3) the development of new centres of research (especially Alexandria) and of institutions (such as its Museum and Library), and (4), connected with the last point, the increase in kingly patronage.

First and most obviously, the science of the Hellenistic world is not a purely Greek phenomenon. The cross-fertilization between Babylonian and Greek astronomy, especially, is increasingly important from the fourth century B.C. onwards. Thus in the second century Hipparchus was able to draw extensively on Babylonian data, and the only astronomer we know to have followed Aristarchus of Samos in adopting the heliocentric theory was Seleucus, a Chaldaean or Babylonian from Seleuceia, who was active around 150 B.C.

Even in the classical period there were fairly well-defined distinctions between 'philosophers', 'mathematicians' and 'doctors'. Yet as practised, notably by Aristotle, philosophy embraced a wide range of what we should call scientific enquiries, both physical and biological, all of which were considered to make an important contribution to the

[1] The main sources for the aspects of Hellenistic science discussed in this and the next four sections are the substantial extant works of Theophrastus, Epicurus, Euclid, Aristarchus, Archimedes, Apollonius, Hipparchus, Strabo, Dioscorides and Hero of Alexandria, together with our chief ancient secondary sources, notably Ptolemy, Pappus, Proclus, Simplicius and Philiponus. For a number of important theorists we have to rely largely or exclusively on such secondary material. This applies to Strato, to the early Stoics, Zeno, Cleanthes and Chrysippus, to Eratosthenes, and especially to the medical writers. Although not a single complete treatise of Praxagoras, Herophilus or Erasistratus has survived, we can draw on the extensive reports and quotations in Celsus, Rufus, Soranus and especially Galen.

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knowledge that the philosopher should attain. In the post-Aristotelian period, both Epicureanism and Stoicism certainly included 'physics' as one of the three branches of 'philosophy' (the other two being logic and ethics). Yet physical enquiry was, in their view, to be conducted with the narrower purpose of freeing the philosopher from fear and anxiety, and that enquiry consequently concentrated first on element theory – the ultimate constitution of material objects – and secondly on the explanation of strange or potentially frightening natural phenomena. No Epicurean and none of the early Stoics made, so far as we know, any significant original contribution to such sciences as astronomy or physiology, although both these subjects were being developed to quite high levels of sophistication in the fourth and third centuries. It is true that some scientists, such as Eratosthenes, had interests in a wide range of non-scientific subjects (though his ancient nicknames Pentathlos and Beta suggest that he was seen not just as a polymath but as not supreme in any field). But as the various sciences increased in technicality, so it generally became the pattern for individual scientists to focus their attention on one or a group of closely related disciplines. While this specialization brought benefits in the greater concentration of effort by particular individuals on particular problems, it was also accompanied by an increase in problems of communication and the fragmentation of studies that had all, under Aristotle, been considered parts of natural philosophy. Outside the Hellenistic philosophical schools, practising scientists rarely developed explicit, let alone original, philosophies of science, although the medical sects are something of an exception.

The founding, during the course of the fourth century, first of Plato's Academy and then of Aristotle's school, the Lyceum or Peripatos, had far-reaching significance not just for what may be called higher education, but also for scientific research. The Library and Museum at Alexandria, founded by Ptolemy Soter at the beginning of the third century, were modelled on and influenced by these predecessors – especially the Lyceum – but they take the development a step further. Like the Academy and the Lyceum, the Alexandrian Museum was a community of scholars working, and to some extent living, together. But the Museum differed first in that it was not – at least not primarily – a teaching institution, but one devoted rather to research and scholarship, and secondly in that whereas the Academy and Lyceum were mainly self-supporting, the Alexandrian Museum and Library were maintained entirely by funds provided by the Ptolemies.

The chief subject that benefited from the cultural policies of the Ptolemies was not science, but literature, including philology and literary criticism. But mathematics, the life sciences and even engineering were also, as we shall see, beneficiaries. It was thanks largely to this

support that Alexandria became pre-eminent in many branches of scientific research in the third century, even though Athens remained supreme throughout antiquity in philosophy. Even Strato, who worked for a time in Alexandria, returned to Athens after Theophrastus' death to take up the headship of Aristotle's school. Some of the cultural ambitions of the Ptolemies were emulated by other rulers – notably by the Attalid dynasty at Pergamum – and Museums and Libraries were set up in other cities. Nevertheless, although the level of patronage available to scientists (among others) increased in the third century, it was still the case – as it was throughout antiquity – that the economics of scientific research were precarious, and many of the most eminent scientists were either men of independent means or earned their livings – or supplemented their incomes – by practising, for example, as doctors or as engineers.

In the four sections that follow, the emphasis will be on illustrating the distinctive features of Hellenistic science and on the question of the comparative successes and failures in the application of theoretical ideas to practical ends. Much of the complexity of Hellenistic science will thereby be omitted or glossed over, and for the details of the development of scientific thought in the period reference must be made to the books and articles specified in the bibliography.

I. PHYSICS

The Greek term *physike* (φυσική) covers the whole of the study of nature and to deal, as we shall, with what we call physics together with aspects of mechanics and chemistry but in separation from the life sciences is to employ a distinction that the ancients would not have admitted.

Both Theophrastus and Strato, who in turn succeeded Aristotle as head of the Lyceum (in 322 and *c.* 287 respectively), made important and original contributions to several specific fields of enquiry which we shall be considering in due course. But although both were critical of Aristotle's element theory, Theophrastus' work stayed very much within its framework, and though Strato's physical doctrines were more eclectic (he assumed that the underlying structure of matter is particulate), he held that the fundamental principles are the two primary qualities, hot and cold, a view that clearly owes much to Aristotle.

Neither Theophrastus nor Strato, in fact, produced a comprehensive physical theory to rival Aristotle's, based on the primary qualities hot, cold, dry and wet, and the four simple bodies, earth, water, air and fire. The two main alternatives to Aristotle's theory available in the late fourth century were those of the Epicureans and the Stoics. On the fundamental question of the structure of matter, the Epicureans and

Stoics advanced in certain respects precisely antithetical positions, the Epicureans insisting that matter, as well as space and time, all consist of indivisibles, the Stoics maintaining that all three are continua. The arguments on either side are mainly abstract and dialectical: the empirical data that were deployed were mostly well-known facts or what passed as such, not the product of independent research. But, as we shall see later, research relevant to such questions as the existence of the void was carried out, though not by members of these philosophical schools.

How well known the treatises of the Aristotelian Corpus were in Athens at the end of the fourth century is disputed. It is likely that Aristotle was then known principally from his more literary works, now lost. Yet it seems clear that in taking over the atomic theory from its original fifth-century proponents, Leucippus and Democritus, Epicurus adapted it to meet some of the objections it had encountered, notably from Aristotle. On two points where the theory of Democritus may have been indefinite or open to attack, Epicurus suggested clarifications or modifications. (1) He distinguished clearly between physical and conceptual divisibility. The atoms are physical minima – the unsplittable units of which physical objects are composed – but they are conceptually divisible: the atom has size and parts. However, in addition to, but distinct from, the physical minima, he postulated ultimate conceptual indivisibles. (2) The primary properties of the atoms now definitely include not just shape, arrangement and position (specified by Aristotle as the primary differentiae in fifth-century atomism) but also weight. In the pre-cosmic state atoms all travel in the same direction ('downwards') in the void. Moreover, whereas Aristotle had held that the heavier the body the faster it falls, Epicurus maintained that in the void speed does not vary with weight. To effect the first collision between atoms and thus initiate the process that leads to the formation of worlds as we know them, Epicurus postulated the swerve: an atom deviates from the vertical by the smallest possible amount. There is no cause for this deviation: it is simply an effect without a cause. Moreover, this postulate had not just a cosmological, but also an ethical significance. Quite *how* by this means Epicurus secured free will is controversial: but *that* he did so is clear.

The ultimate ethical motivation of Epicurus' physics emerges clearly also in many of his discussions of particular natural phenomena. 'There is no other end to the knowledge of things in the sky . . . than peace of mind.'[2] Adopting a principle of plural explanations, he insisted that if several possible explanations of a single phenomenon suggest themselves, then so long as none of them is positively contradicted by the evidence all should be allowed to stand. Admirably undogmatic in

[2] Epicurus, *Letter to Pythocles* 85.

theory, and indeed in practice when applied to such obscure problems as the nature of thunder and lightning, this principle was sometimes invoked either to block further investigation or to dismiss the results his contemporaries or predecessors had obtained, as when he asserts that a plurality of explanations must be entertained for such phenomena as the phases of the moon. The unscientific, indeed anti-scientific, aspects of Epicureanism become evident when he dismisses further research as futile and accuses astronomers not just of dogmatism but of superstition and mythology because they sought single explanations.[3]

The underlying motive for the study of natural phenomena was the same for the Stoics as for the Epicureans, namely the attainment of peace of mind. Otherwise, however, the two schools were in fundamental disagreement on almost every important issue in physics. Whereas Epicurus held that atoms and the void alone exist, the Stoics denied that there is a void within the world, although outside it there is infinite void. They rejected the idea that the void is necessary to explain motion. The world is a plenum, but that does not prevent motion taking place within it. As fish move through water, so any object can move through the plenum conceived as an elastic medium.

In contrast to the essentially quantitative theory of the atomists, in which qualitative differences are reduced to differences in the shape, arrangement and position of atoms, the physics of the Stoics was fundamentally qualitative. The starting-point of their cosmology is a distinction between two basic principles, the active and the passive. The passive is quality-less substance or matter. The active is variously identified as cause, god, reason, **πνεῦμα** (breath or vital spirit) and fate. *Both* these principles are corporeal, and to describe the relation between them the Stoics used the idea of the total inter-penetration or mixture of substances – **κρᾶσις δι' ὅλων**. The active principle is thus thought of as inherent in the whole world and permeating every part of it.

The physics of Epicurus and the early Stoics (Zeno, Cleanthes and Chrysippus) were abstract systems based primarily on reflection on the problems of the ultimate constitution of matter. Although both schools proposed causal explanations of many astronomical, meteorological and biological phenomena, neither engaged in empirical research to any significant extent, though among the later Stoics Posidonius (*flor. c.* 80 B.C.) is something of an exception to this. Nevertheless, the late fourth-century debate brought into the open the issue between two fundamentally opposed, but complementary, conceptions of matter: atomism and continuum theory. Either matter exists in the form of discrete particles, separated by void, or it is a continuum of inter-communicating parts. With each conception is associated a different doctrine of movement – a

[3] Epicurus, *Letter to Pythocles* 87.

particle, and a wave, theory: either motion is the transport of material particles through the void, or it is the transmission of a disturbance in an elastic medium. As so often in earlier Greek philosophy, cosmological debate of a highly speculative order thus generated ideas of considerable importance and lasting influence in physical theory.

The contrast between cosmological speculation and detailed empirical investigations into various branches of physics is marked. Yet contemporary with Epicurus and Zeno there were natural philosophers who engaged to good effect in the latter. In the Lyceum, especially, first Theophrastus (Epicurus' senior by some thirty years) and then Strato did so, and although after Strato's death (*c.* 269) the importance of the Lyceum declined, this tradition was carried on by others elsewhere, notably by Philo of Byzantium (around 200 B.C.) and Hero of Alexandria (probably first century A.D.).

Much of Theophrastus' work may be seen as a continuation of Aristotle's researches. He evidently collaborated closely with Aristotle in many areas of scientific enquiry and although we must certainly reject the extreme view that he was responsible for most of what appears in our Aristotelian Corpus, parts of the *Historia animalium* have plausibly been thought to owe as much to him as to Aristotle himself, and we shall be considering Theophrastus' undoubted botanical works later.

Two of his shorter treatises deal with physical problems. In *On Fire* he hits on a fundamental objection to Aristotle's doctrine of fire as a simple body. Unlike air, water and earth, fire requires a substratum. 'Everything that burns is always as it were in a process of coming-to-be and fire is a kind of movement.'[4] 'It seems absurd to call this a primary element and as it were a principle, if it cannot exist without matter.'[5] Yet although Theophrastus thus exposes an important weakness in Aristotle's doctrine, he attempts no new element theory himself. He does, however, provide some important data relevant to the investigation of what fire is, concerning, for example, the different ways in which fire may be made or extinguished, even if he draws back from the question of determining its nature.

In *On Stones*, too, the framework of Theophrastus' account is derived from Aristotle, in that he classifies 'things found in the earth' into two main groups, those (like the metals) in which water predominates, and those (the stones and earths) in which earth does. But within this framework he attempts an account of the different kinds of stones, distinguishing them by colour, hardness, smoothness, solidity, 'weight' (that is specific gravity) and their reactions to other substances or processes, especially fire and heat. The range of data his discussion encompasses is remarkable: thus he often gives detailed information

[4] Theophr. *On Fire* 51.24ff. [5] Theophr. *On Fire* 51.30–1.

about the precise localities from which a particular kind of stone, earth or metal comes. He pays attention to – and provides us with interesting information concerning – contemporary technology. His description (section 16) of the mining of what is probably lignite contains our first extant Greek reference to the use of a mineral product as fuel. Sections 45–7 on the touchstone contain our first account of a method of determining the precise proportions of the constituents of an alloy. Among the processes which he describes as having recently been discovered are the production of red ochre and the extraction of cinnabar, and at the end of his brief account of how quicksilver is produced he remarks 'perhaps several other such things could be discovered'. The enquiry is certainly undertaken with theoretical, not practical, interests in mind: Theophrastus was no alchemist (cf. below, p. 330). There is no evidence of his attempting to conduct systematic experiments to advance the classification of stones and earths, let alone for technological motives. Nevertheless, within the limits of the aims he set himself, he collects and attempts to bring into systematic order a considerable body of mineralogical and petrological data. Again, whereas many ancient writers on stones and metals deal at length with their magical properties, especially their supposed therapeutic powers, Theophrastus' discussion is generally (though not entirely) free from such preoccupations.

The work of Theophrastus' successor, Strato, is much harder to reconstruct since we have no single complete treatise and have to rely on fragmentary reports and paraphrases in later writers. We know that he wrote on a wide variety of topics, including zoology, pathology, psychology and technology. Most of our information concerning his work relates to certain physical and dynamical investigations, notably in relation to the two problems of gravity (or as the Greeks called it the nature of the heavy and the light) and the void. Against Aristotle's view that there are two natural tendencies, one of heavy bodies towards the centre of the earth, and the other of light ones away from it, Strato argued that a single downward tendency can account for both movements, the upward movement of fire and air being explained by their being displaced by the downward motion of heavier bodies. More importantly, he is reported to have attempted to establish the phenomenon we call acceleration empirically, adducing the evidence of falling water and of the impact of stones dropped from different heights to support the conclusion that a falling body 'traverses each successive space more swiftly'.[6]

On the void, too, he attempted to deploy empirical, indeed experimental, evidence. It is generally agreed that an extended passage in the

[6] Simpl. *in Phys.* 916.18ff.

introduction to Hero's *Pneumatica* is derived partly from Strato. This contains first a simple test in which an empty vessel is inverted and pressed down into water in order to demonstrate the corporeality of air, and then a series of more striking experiments to show that a continuous vacuum can be produced artificially. A hollow metal sphere with a siphon let into it is used to show first that air can be forcibly introduced (this is taken to establish that a 'compression of the bodies in the sphere takes place into the interspersed vacua' in the air it contains[7]) and secondly that air can be forcibly withdrawn from the sphere (taken to show the artificial production of a continuous vacuum). As is often the case with ancient experiments, the tests are inconclusive. The results are interpreted already in terms of the theory they purport to demonstrate, and those who denied the void could, no doubt, have explained the phenomena described by appealing to the elasticity of air. Yet the attempt to adduce new empirical evidence relevant to the largely dialectical controversy on the existence of the void is notable and characteristic of Strato's approach.

The type of empirical investigations found in Strato continues in Philo and Hero. They too were interested in such problems as the existence of the void, but much of their discussion is devoted to the description of mechanical devices of various kinds, including some which involve the use of mathematics which we shall be considering later (pp. 336–7). Here we may concentrate on those that employ pneumatic or hydraulic principles. Many, even the majority, of these are gadgets explicitly designed to amaze or amuse. Hero's *Pneumatica*, for instance, describes more than two dozen gadgets constructed with secret compartments and interconnecting pipes and siphons that enabled strange effects to be produced – Magic Drinking Horns from which two different liquids can be poured, for example, or Magic Mixing Vessels that replenish themselves (from a hidden reservoir) as they are emptied. One toy even uses the power of steam: a hollow ball with bent tubes attached is made to rotate on a pivot over a cauldron of water which is heated to make steam – a primitive reaction turbine.

But some of the devices are meant not – or not just – 'to produce astonishment and wonder', but to 'supply the most necessary wants of human life' (as Hero puts it[8]) and some are of practical consequence. Several of the most interesting inventions are associated in our sources with the name of Ctesibius, an Alexandrian engineer active in the last quarter of the third century B.C. whose own mechanical treatise has not survived. Thus Vitruvius ascribes to him a force pump, incorporating a system of valves, cylinders and pistons to deliver water under pressure, and a development of the clepsydra, the constant-head water-clock.

[7] Hero, *Pneumatica* Proem 16.23–4. [8] Hero, *Pneumatica* Proem 2.18ff.

Ancient technology, while essentially conservative, was not as totally stagnant as has often been claimed. The literary and archaeological records provide evidence of improvements in certain aspects of food technology and agriculture, in ships and sailing, in areas of metallurgy and in what we should call chemical technology, although such improvements are usually hard or impossible to date with any precision. These developments generally owe more to the trial and error adjustments of the craftsmen themselves than to the application of the theoretical investigations of those who studied mechanics. Nevertheless, the evidence of Philo and Hero especially shows that there was some limited interaction between theory and practice.

Moreover, an important text in Philo indicates that some of the research carried out or at least reported by the mechanical writers received state support. In his *Belopoeica* he describes the investigation of the construction and design of catapults incorporating the torsion principle to exploit the power of skeins of twisted hair or sinew (see further below, p. 358) and he contrasts the crude trial and error methods of earlier workers with the systematic experiments of their successors. Whereas some of the 'ancients' had begun to realize that the key factor in catapult construction was the diameter of the bore (the circle that receives the twisted skeins), their attempts to determine the correct size for different weights of shot had been haphazard. Only recently, Philo says, the right formula had been arrived at thanks to systematic trials increasing and diminishing the diameter of the hole and observing the results. This success, he continues, was achieved by Alexandrian engineers 'who received considerable support from kings who were eager for fame and well disposed to the arts and crafts'.[9]

The circumstances of this case were evidently exceptional. There were powerful motives for promoting research in military technology that did not apply elsewhere – not that we should suppose that the ancients were entirely lacking in ambition to improve technology in other fields as well, or that there was any general shortage of inventive talent (Ctesibius' work and Hero's gadgets show that). On the other hand that talent usually worked in some isolation and against a background of the largely conservative tendencies in the ancient arts and crafts. Throughout antiquity, and not just in the Hellenistic period, the ancients were slow to explore *as a matter of course* the practical applications of theoretical advances in science, and they more often saw theoretical work as an end in itself rather than as a means to be justified by its eventual practical applications. But if ancient values certainly did not favour systematic support of co-ordinated and methodologically sophis-

[9] Philo, *Belopoeica* 50.37ff.

ticated technological research, Philo's text shows that in one instance, at least, such research was encouraged by the Ptolemies.

In the study of air and its effects the approach adopted by the Stoics and Epicureans contrasts with that of Strato and later mechanical writers. In our final topic in this section, chemical technology, the gap between practitioners with speculative tendencies and artisans is more marked still. Although on the question of the classification of natural substances little advance was made on Theophrastus' work, extensive proto-chemical literature exists from the late Hellenistic and Imperial periods, especially chemical papyri dating from the third century A.D. onwards, and a variety of alchemical texts going back some two centuries earlier.

We may distinguish broadly between two principal types of investigation, corresponding roughly to these two groups of texts. On the one hand there is what Needham has called aurifiction,[10] the production of imitations of gold – with or without an intent to deceive the customer – by men who were themselves under no illusions that what they were producing was gold. They could not afford to be under any illusions on the subject, for their profit depended on the difference between the real thing and the imitation, and they were usually, one presumes, in a position to test for gold, not just by the touchstone, but by cupellation.

On the other hand there is aurifaction, **χρυσοποιία**, the attempt to produce 'philosophers' gold', to transmute other substances into a gold that was meant to be indistinguishable from, as good as, or better than, natural gold. This was the aim of men who were influenced by philosophical, not to say mystical, beliefs, concerning, especially, the sympathies and antipathies between things. Unlike the artisans engaged in aurifiction, those who practised aurifaction remained, one must suppose, either ignorant of, or indifferent to, the test of cupellation. The appeal to that test would immediately have revealed that their products were not *ordinary* gold. Both types of investigation were practical in orientation in that they were each directed to obtaining certain end-products. Moreover, both made important contributions to the development of chemical techniques and equipment – particularly in connexion with the processes of distillation and sublimation. At the same time they provide a striking illustration of the fragmentation of research and of the conceptual barriers between men working in the same or similar fields.

II. MATHEMATICS AND ITS APPLICATIONS

Already in the mid fourth century B.C. Plato and Isocrates distinguished between two main types of reasons for studying mathematics, that is

[10] Needham 1974, 10ff.: (J 103).

broadly the practical and the theoretical, though they differed radically in their evaluations of these two. That distinction is reflected in the extant sources for Hellenistic mathematics and it is echoed by later commentators, such as Pappus (early fourth century A.D.) and Proclus (fifth century A.D.). While the works of Euclid (*c.* 300 B.C.), Archimedes (287–212) and Apollonius (*c.* 210), especially, provide us with rich evidence for achievements both in what we would call 'pure' mathematics and in the applications of mathematics to the exact sciences, some of the works of Hero of Alexandria represent, as we shall see, a second, in many ways distinct, more practically oriented, strand of Greek mathematical work.

The problem of assessing Euclid's originality is severe. Almost all the work of his predecessors is lost, and although Plato and Aristotle offer valuable insights into fourth-century mathematics, the reconstruction of pre-Euclidean contributions otherwise depends very largely on what can be inferred from Euclid himself or from later commentators. Nevertheless, certain points are reasonably clear. First there can be little doubt that the vast majority of the theorems in the *Elements* were known before him. His debts to Theaetetus, for example in the study of incommensurables in Book X, and to Eudoxus, to whom is attributed the general theory of proportion in Book V, are particularly important, and the work of identifiable or unnamed predecessors underlies every book of the *Elements*. Secondly, we know that attempts to systematize parts of mathematics go back to Hippocrates of Chios in the late fifth century: he was the first to compose a treatise of *Elements*, this being the term used of the primary propositions from which others were derived. Moreover, between Hippocrates and Euclid we hear of a number of other writers, such as Archytas and Theaetetus, who, in Proclus' words, 'increased the number of theorems and progressed towards a more scientific arrangement of them.'[11]

Nevertheless, what no one before Euclid appears to have done is to have attempted so comprehensive a systematization of the whole of mathematical knowledge. The *Elements* begins with a statement of assumptions, distinguished into three kinds: 'definitions', 'common opinions' and 'postulates'. These three clearly bear a close resemblance to those that Aristotle identifies as the starting-points of demonstrations in his formal logic, namely definitions, axioms and hypotheses. How far Aristotle is drawing on pre-Euclidean mathematics, and how far Euclid in turn may be drawing on Aristotle, are controversial questions. But there is no definite evidence that any earlier mathematician had drawn clear distinctions between different kinds of starting-points, and what Plato has to say about the mathematicians' use of 'hypotheses' in the *Republic*[12] suggests that at that time there may have been some lack of determinacy

[11] Procl. *in Euc.* 66.15ff. [12] Plato, *Resp*, 510cff.

in the notion. Moreover, among the particular assumptions that Euclid specifies is the famous parallel postulate, which states that non-parallel straight lines meet, and it is commonly and perhaps rightly thought that the inclusion of this among the postulates may be due to Euclid himself. His doing so was criticized extensively in antiquity on the grounds that the proposition should be proved. But in modern times, especially since the development in the nineteenth century of alternative geometries, the wisdom of his including as a postulate the fundamental assumption underlying what we call Euclidean geometry has received greater recognition.

After the statement of assumptions the *Elements* offers deductive proof of a wide range of theorems and the solution of a variety of problems of construction. Although judged by modern criteria some of the proofs presented have their shortcomings, in that, for example, they incorporate assumptions or intuitions that would now be deemed to require justification or defence, the rigour and economy achieved are, on the whole, remarkable. It was for this, pre-eminently, that the *Elements* subsequently became a model of method not just for mathematics but for science as a whole, and secured a place in mathematical education from which it has been displaced only in the present century.

Both Archimedes and Apollonius were creative mathematical geniuses of a far higher order than Euclid. Archimedes' interests were particularly wide-ranging. His extant treatises relate to arithmetic and geometry, statics and hydrostatics, but we know also of investigations in optics, astronomy and engineering. So far as his work in pure mathematics goes, *The Sand-Reckoner*, for instance, develops a new notation for expressing very large numbers. In the elementary treatise *Measurement of the Circle* he elaborates a method used by Euclid before him, based on Eudoxus' method of exhaustion. He determines the area of a circle by inscribing successively greater regular polygons within it and circumscribing successively smaller regular polygons outside it. These processes can be continued indefinitely – the difference between the areas of the polygons and that of the circle can be made as small as desired – not that the Greeks admitted the identification of either polygon with the circle.

A more strikingly original aspect of Archimedes' methods is his application of mechanical concepts to geometrical problems. Thus arguments based on principles in statics, in particular the law of the lever, are brought to bear on the problems of determining unknown areas or volumes, which can be thought of as *balanced* with known areas or volumes at particular distances from a fulcrum. Yet another even more important feature is one that he refers to himself in his *Method of Mechanical Theorems*. There he writes of a certain method by which

certain problems can be investigated, even if the method in question does not, in his view, constitute a proof: the theorems discovered by the method have subsequently to be proved by rigorous geometrical methods. The method itself involves conceiving of a plane figure as composed of a set of parallel lines indefinitely close together and then thinking of these lines as balanced by corresponding lines of the same magnitude in a figure of known area. What Archimedes thereby performs is what we should call an integration, even if he lacks a general theorem for integration. It is, too, particularly remarkable that Archimedes is emphatic that his new method does not itself yield a demonstration. In the *Method* the illustration he gives is the proposition that the area of a segment of a parabola is four-thirds the triangle with the same base and the same height: but he follows the application of his method with a reference to the strict demonstration of the theorem that he had given in *Quadrature of the Parabola.*

In *On the Sphere and Cylinder*, *Quadrature of the Parabola*, and *Spirals* Archimedes adopts a Euclidean style of presentation, setting out, where necessary, his assumptions and definitions and proceeding in a rigorous deductive fashion. But he, like Apollonius after him, is now able to build on the *Elements* itself, taking many of its results as already demonstrated. Apollonius, in turn, takes a further area of mathematics forward in the one treatise of his that is extant, his masterpiece *Conics*, a comprehensive discussion of the three types of conic section, ellipse, parabola and hyperbola, including such questions as the construction of conics from certain data, tangents, focal properties, intersecting conics and the like.

Pure mathematics at the level at which it was practised by Archimedes and Apollonius was the concern of a tiny minority. But the prestige of mathematics depended rather on the appreciation of the rigour and certainty of its results – and that was easy enough to grasp even in elementary examples. It is likely that, like other scientists, mathematicians were the beneficiaries of royal patronage, though to what extent is a matter of guesswork. The evidence of Euclid's connexion with the Ptolemies is anecdotal, but we are reliably informed that the mathematician, geographer and polymath Eratosthenes was made head of the Library under Ptolemy Euergetes. Archimedes, however, was related to the ruling family at Syracuse, and his presence in the ranks of the foremost mathematicians may serve as a reminder that many of those who embarked on scientific enquiries were men of means and leisure.

This leads us towards the complex question of the applications of mathematics, a topic which can be discussed in two parts, first the applications of mathematics to the exact sciences (applied mathematics in this sense still being theoretical), and secondly the practical applications of mathematics in mechanical devices and in engineering.

Already in the fourth century Aristotle speaks of astronomy, optics and harmonics as the more physical of the mathematical studies and in all three cases the mathematical investigation of the subject-matter was well established by the end of that century. Later in the Hellenistic period other branches of enquiry were to be added to the list, especially statics and hydrostatics by Archimedes. Astronomy, together with mathematical geography, is important enough to be dealt with in a separate section (below, pp. 337–47). Euclid's *Optics* is our first extant treatise on the subject. Characteristically it begins with a statement of assumptions, which include such idealizations as that 'the figure contained by a set of visual rays is a cone of which the vertex is at the eye and the base at the surface of the subject seen'.[13] Again characteristically it proceeds by treating the subject-matter in purely geometrical terms.

Similarly in harmonics, where the Euclidean *Sectio canonis* is one in a long line of specialist treatises on the subject, though whether it was written by Euclid himself is disputed, the reduction of the audible concords to simple numerical relationships goes back at least to the fifth-century Pythagoreans, if not to Pythagoras himself, and work on the analysis of musical scales continues throughout the Hellenistic period. It is interesting, however, that at the end of the fourth century Aristoxenus reports an epistemological debate in which those who were for reducing harmonics to a purely mathematical subject, and who rejected the senses as inaccurate, were opposed by those who insisted rather that sense-perception is the ultimate criterion. Aristoxenus, for his own part, claims to steer a middle course, maintaining that the enquiry depends on the two faculties of hearing and the intellect and emphasizing that, unlike the geometer, who makes no use of sense-perception, the student of musical science must have a trained ear.[14]

It is in line with such reductions of physical phenomena to exact mathematical relationships that Archimedes investigates both statics, in *The Equilibrium of Planes*, and hydrostatics, in *On Floating Bodies*. The treatise *Mechanica* in the Aristotelian Corpus had already discussed a number of problems concerned with balances and the lever, often with, as we shall see, an emphasis on practical issues. What is quite new in Archimedes is the rigorous deductive proof of the basic propositions of statics. He begins by stating such postulates as that 'equal weights at equal distances are in equilibrium and equal weights at unequal distances are not in equilibrium but incline towards the weight which is at the greater distance',[15] and he then proceeds to demonstrate a series of simple propositions, including in proposition six and seven the law of the lever, first for commensurable and then for incommensurable

[13] Euc. *Optics* Def. 2. [14] Aristox. *Harm.* II.32–3.

[15] Archimedes, *The Equilibrium of Planes* 124.3ff.

magnitudes. The rest of Book I and Book II deal with the problems of determining the centres of gravity of various plane figures such as a parallelogram or parabolic segments. The problems are, throughout, formulated in ideal, mathematical terms. Friction, the weight of the balance itself, every extraneous physical factor is discounted. The key physical assumptions (which Mach claimed already presuppose the law of the lever) are contained in the postulates. But these once assumed, the subsequent discussion is geometrical throughout. Archimedes, one may say, treats statics as a branch of geometry and the whole is an exercise in deductive proof on the model of Euclid's *Elements*.

Moreover, the same is true also of the hydrostatical treatise, *On Floating Bodies*. Again he begins with a postulate setting out the properties of fluids that have to be assumed. Again the proofs – including the proof of 'Archimedes' principle' itself in proposition seven – proceed deductively and again the development of the investigation is geometrical. After considering propositions concerning segments of a sphere in Book I, Archimedes turns, in Book II, to problems concerning paraboloids of revolution, investigating the conditions of stability of segments of paraboloids of varying shapes, and of varying specific gravities, in a fluid. It has been suggested that this focus on paraboloids reflects a practical interest in ship-building (the cross-section of the hull of a ship being, approximately, a parabola[16]). Yet Archimedes himself makes no such connexion and his idealized mathematical study is as far away as could be from matters of practical concern.

We find, then, that in a number of subjects Hellenistic scientists achieved notable successes in turning the enquiry into an exact science. These are among the most striking developments of Hellenistic, even of Greek, scientific endeavour. When we turn to the evidence for practical applications of mathematics, the record is a good deal thinner. First, as already noted, there is a strand of mathematical enquiry itself that overlaps, to be sure, with the Euclidean, but is often distinctly more practical in its concerns. Although Hero of Alexandria himself is now generally dated to the first century A.D., his writings – like Euclid's – evidently draw on a rich and long tradition, in some cases including aspects of Babylonian and Egyptian mathematics. Thus Hero's *Metrica* deals with problems of mensuration, for the solution of which geometry is certainly used, but which often have a practical significance, as when he discusses, for instance, the determinations of areas and volumes.

Our extant evidence for the practical investigation of mechanical problems begins a good deal earlier than Hero, with the Aristotelian *Mechanica*. The practical orientation of some of the discussions in this

[16] Cf. Landels 1978, 191. (J 94).

treatise is in marked contrast to Archimedes' *The Equilibrium of Planes*. The author (perhaps a pupil, certainly a follower, of Aristotle) considers such topics as why larger balances are more accurate than smaller ones, why longer bars are moved more easily than shorter ones round the same capstan, even why it is easier to extract teeth using a forceps than without, along with many other simple applications of the lever, the wedge, the pulley and the windlass.

Mechanica thus discusses four of the simple 'powers' known to the ancients. All four had been used in one form or another long before the fourth century. Yet the literature that begins with *Mechanica*, continues in Hero's mechanical treatises and goes on into late antiquity with such works as the eighth book of Pappus' *Mathematical Collection* is evidence of the interest shown both in the mathematical analysis of a number of mechanical problems and, conversely, in the practical applications of mathematical ideas to different fields. Thus both Hero and Pappus tackle the problem of the analysis of the forces acting on weights on an inclined plane. Several passages in Hero deal with the question of how to shift a weight of a given magnitude with a force of a given magnitude using either compound pulleys or levers, or toothed or cogged wheels.

The fifth 'power' treated in the mechanical writers, the screw, provides perhaps the most striking example of the application of mathematical knowledge. Far more than any of the other simple powers, the screw depends on working out and applying a mathematical construction. Moreover, unlike the other four, it appears to have been developed first, in its various ancient forms, during the Hellenistic period. It may have been used first in the water-lifting device still named after Archimedes (there is an ancient tradition that he invented this in Egypt[17]), but in Hero we also find it applied in presses, both the single- and the double-screw press, and in devices for lifting heavy burdens. Hero also provides evidence for ancient screw-cutting machines and discusses how to make a cog-wheel with a given number of teeth to fit a given screw.

Some of the devices in the mechanical literature are scarcely practicable. The frequent discounting of the effects of friction, especially, is in line with the simplification of physical problems which we have remarked on elsewhere, but it turns the discussion into a highly idealized one. Yet the point should not be exaggerated. The problem of confirming the use of cog-wheels, for example, in practice is severe, for most such devices would have been made in perishable materials. Yet the bronze Anticythera instrument shows that gear-wheels were incorporated into practical instruments, even if in this case they are not made to do much mechanical work: the object is a calendrical computer

[17] Diodorus 1.34: v.37; Athenaeus v.208F; Plates vol., pl. 260.

in which a system of differential gears is used to represent the sidereal motions of the sun and moon.[18]

When Plutarch, in a much quoted passage, reports that Archimedes despised technology and 'regarded the work of an engineer and every art that ministers to the needs of life as ignoble and vulgar',[19] this certainly represents attitudes that were common and influential among the educated cultural élite to which Plutarch himself belonged. Whether this correctly represents Archimedes' own views is another matter, since it would appear that his interest in mechanical devices was extensive and not confined merely to the domain of military technology and to his involvement in the construction of machines for the defence of Syracuse (cf. below, pp. 358–9). We must repeat that although the evidence for the interaction of theory and practice is limited, it is not negligible. That there were not greater practical results from the efforts of the mechanical writers is, once again, a matter to be referred to their comparative isolation and lack of systematic support, factors which, in turn, relate, as we have said, to the dominant values of ancient society.

III. GEOGRAPHY AND ASTRONOMY

Both geography and astronomy have on the one hand a descriptive and on the other a theoretical, mathematical aspect. In late antiquity Ptolemy,[20] for instance, explicitly distinguished what he called 'chorography' – descriptive geography dealing with the nature of lands, region by region – from geography proper, the mathematical study concerned principally with the problems of projection, although, like many other important ancient geographers, Ptolemy himself combined an interest in both fields. From the very beginning of Greek historical writing Hecataeus and Herodotus had concerned themselves with the description of countries as well as of events, and this tradition continued in, for example, the 'universal' historian Polybius. The most comprehensive extant treatise devoted primarily to descriptive geography is the work of Strabo (first century B.C. – first century A.D.), though his extensive references to his predecessors – especially Eratosthenes, Hipparchus and Posidonius (from the third, second and first centuries B.C. respectively) – enable us to reconstruct some of their contributions. These geographical studies were not just the product of individual curiosity and research, but were at least sometimes undertaken for reasons of state or stimulated by royal patronage. An incidental remark in Pliny tells us, for instance, that Dicaearchus, a pupil of Aristotle, undertook the measurement of the height of certain mountains charged by, and presumably with the

[18] See Price 1974: (J 116); Plates vol., pl. 261.
[19] Plut. *Marc.* 17.4. [20] Ptol. *Geog.* 1.1.3.3ff.

support of, 'the kings',[21] though Pliny does not specify who these were.

Mathematical geography, too, goes back to the classical period. The sphericity of the earth was known before Aristotle, who demonstrates it in the *De Caelo*[22] partly from the shape of the earth's shadow in lunar eclipses and from the changes in the positions of the stars as observed from different latitudes, and who provides our first extant estimate of its circumference, namely 400,000 stades, although he does not specify how this figure was arrived at – nor is it certain which of several possible 'stades' of different lengths he was using. A division of the globe into zones ('arctic', 'temperate' and 'torrid') is also pre-Aristotelian, but not long after him was improved on. Even though none of Eratosthenes' books has survived, we know that his interests were extensive: they included philology and literature as well as mathematics, astronomy and geography. He appears to have been responsible for the first detailed map of the world based on a system of meridians of longitude and parallels of latitude. We are told by Cleomedes[23] not just the figure that Eratosthenes gave for the circumference (250,000 stades: again the 'stade' in question is disputed) but also how he arrived at it, namely on the basis of a comparison of the shadow cast at noon on the day of the summer solstice at two locations, Syene and Alexandria, assumed to lie on the same meridian circle. While at Syene the gnomon made no shadow, at Alexandria it gave one of seven and one fifth degrees. Given an estimate of the distance from Syene to Alexandria – which he took to be 5,000 stades – he could obtain the circumference of the earth by simple geometry.

The accuracy of the result depended on two factors. The first is the measurement of the gnomon's shadow. Ptolemy was later to note the difficulty of obtaining accurate solstice observations in the *Almagest*,[24] and it may be that it was for this reason that when Posidonius came to make his calculation of the circumference of the earth he adapted Eratosthenes' method and used comparisons not of solstice shadows, but of the observed altitude of the star Canopus.[25] The second, more important, factor was the accuracy of the estimate for the base-line Syene–Alexandria. Assessments of distances over land were notoriously unreliable, so much so that we find Ptolemy, for example, insisting that the locations of places on the earth's surface should, so far as possible, be determined from astronomical data rather than from the reports of travellers[26] – thereby rather reversing the procedure that Posidonius had

[21] Pliny, *NH* II.162.

[22] Arist. *Cael.* II.14, 297b24ff., 30off., 298a15ff.

[23] Cleomedes I.10.94.24ff. Elsewhere, however, a figure of 252,000 stades, giving a round figure of 700 stades per degree, is ascribed to Eratosthenes: Strabo II.34.132; Theon Smyrnaeus 124.10ff.

[24] *Alm.* III.1.196.21ff., 203.12ff.

[25] See Cleomedes I.10.92.3ff. [26] Ptol. *Geog.* I.4.12.4ff.

used to determine the earth's circumference. Nevertheless, whether in Eratosthenes' version or in that of Posidonius, here was a notable application of mathematical principles to a geographical problem. Others were to involve more sophisticated mathematics. By the time we reach Ptolemy in the second century A.D. the problems of cartography – the projection of the sphere on to a plane surface – are discussed with considerable subtlety, the accuracy of different projections being assessed with some care.

It was, however, in astronomy that the greatest successes in the application of mathematics to physical problems were achieved. Two issues, one major, one minor, dominated theoretical astronomy from the fourth century B.C. onwards. The minor one, in the ancients' view – though it has been a dominant topic in some histories of astronomy – was the question of whether the earth or the sun is at the centre of the universe. We know from a report in Archimedes that Aristarchus of Samos, working around 280 B.C., produced a set of what Archimedes calls hypotheses that included the propositions that the fixed stars and the sun remain unmoved and that the earth is borne round the sun on the circumference of a circle.[27] The status of these hypotheses is a matter of some controversy. Plutarch contrasts Aristarchus' position, which he represents as the mere 'hypothesizing' of the idea of the earth's movement, with that of Seleucus who, Plutarch says, also 'asserted' it.[28] But Plutarch himself was no astronomer and his testimony is open to doubt. The report itself confirms, however, that one ancient astronomer at least maintained heliocentricity.

Moreover, we can be sure that – whatever his own reservations about the physics of his hypotheses may have been – Aristarchus himself advanced his position in all seriousness as a possible mathematical model to account for the movements of the heavenly bodies. This is clear from the way the hypotheses are framed as a complete set and in particular from the care with which Aristarchus guards against one major objection to which the heliocentric theory was vulnerable, namely the apparent absence of stellar parallax – that is the shift in the relative positions of the stars as viewed from different points in the earth's orbit round the sun. Aristarchus evidently saw that this objection fails if the stars are sufficiently distant from the earth. He did not attempt to *prove* that they are. Rather he included as one of his initial assumptions, according to Archimedes, that the circle in which the earth revolves round the sun is as a point in relation to the sphere of the fixed stars, that is, that the stars may be thought of as at infinite distance.

Nevertheless, with the sole exception of Seleucus, no other ancient

[27] Archimedes, *The Sand-Reckoner*, 1.4ff., 218.7ff. [28] Plut. *Quaest. Plat.* VIII.1.1006C.

astronomer adopted Aristarchus' suggestion. The two greatest names in third- and second-century B.C. astronomy, Apollonius and Hipparchus, both retained the geocentric view, and so too did Ptolemy. If we may use Ptolemy as our chief source for the arguments that weighed with the astronomers in their rejection of heliocentricity, religion was not an important factor. It is true that the Stoic philosopher Cleanthes is reported by Plutarch to have thought that the Greeks ought to indict Aristarchus for impiety for putting the 'hearth of the universe' (that is, the earth) in motion.[29] But the discussions of the issue in astronomical authors are free from any such idea. Ancient astronomers had, in any case, no Church to contend with, and no Bible with the authority of revealed truth.

The objections to the earth's movement that Ptolemy mentions are partly physical and partly astronomical.[30] The Aristotelian doctrine of natural places starts from the idea that heavy objects, including earth, naturally move towards the centre of the universe. Applying this to the earth as a whole, we arrive at the conclusions that it is at rest in the centre of the world and that it could not be moved except by some immense force capable of overcoming its natural tendency. Secondly, there is the absence of any visible effects of the earth's rotation on solid objects, or even on the clouds, above the earth's surface. It is clear that the counter to this objection – that it is not only the earth, but also the surrounding air that rotates – had been suggested by Ptolemy's time, even if he himself is unimpressed by this defence. Thirdly, the chief astronomical difficulty, which Aristarchus had anticipated by suggesting that the stars may be thought of as infinitely distant, is the absence of stellar parallax. We might conjecture, though we cannot confirm, as a fourth factor, that ancient astronomers recognized that a simple circular movement was inadequate to account for the irregular movements of the sun and moon, where the issue between geocentricity and heliocentricity could be ignored as irrelevant. Given that either eccentric circles or epicycles had to be appealed to in those two cases, ancient astronomers may have assumed that a similar solution to planetary motion was also to be given.

These considerations are, to be sure, of very varying force, but their cumulative effect was felt to be decisive against any suggestion that the earth moves in space. We do not know how closely the opening chapters of Ptolemy's *Almagest* follow Hipparchus' thinking. But so far as Ptolemy himself is concerned, it is clear that he felt that the subsequent astronomical system he develops is securely founded on what he took to be well-established *physical* principles: that system is not just a mathematical construct without any basis in physical reality. His whole discussion betrays a confidence in the absurdity of the suggestion that

[29] Plut. *de Fac.* 6.923A. [30] Ptol. *Alm.* 1.6.21.9ff.

the earth moves and he does not explore or even investigate the consequences of heliocentricity for the problems of planetary motion.

The major issue, in the eyes of ancient astronomers, was that of the explanation of the movements of the sun, moon and planets, especially the irregularities of planetary motion. The model of combinations of concentric spheres, proposed by Eudoxus and adapted by Callippus and Aristotle in the fourth century, failed – among other things – to account for the apparent variations in the distances of the moon and of the planets. The model that replaced this and was to last not only throughout antiquity but down to Kepler was the work of Apollonius of Perge, whose investigations of conic sections have already been mentioned (above, p. 333). He proposed that the motion of the sun, for instance, can be represented either as an eccentric circle (fig. 1), or as movement on the circumference of a circle (an epicycle) whose own centre moves round the earth (fig. 2). It is probable that Apollonius recognized that these two mathematical models can be made equivalent (fig. 3) and he no doubt appreciated that either model could give a simple explanation of the irregularity of the sun's movement, that is the inequality of the seasons, a fact discovered by Meton and Euctemon in the late fifth century B.C. but ignored by Eudoxus (see fig. 4).

It is, however, quite uncertain how far Apollonius applied these models to give detailed solutions to the movements of the sun, moon and planets. According to Ptolemy, not even Hipparchus succeeded in producing such solutions to the problems of planetary motion,[31] although his models for the sun and moon were accurate enough for Ptolemy to base his own theories on them – in the case of the sun with very little modification. Ptolemy himself, working long after Hipparchus, but relying very heavily on his results, provides us in the *Almagest* with the most elaborate example from the whole of extant ancient science of the application of pure geometry to the explanation of highly complex phenomena. It is true that there are points at which he gives us much less information about his data base than we should like; again there are others where his selectiveness of the data to be discussed is transparent, and yet others where he himself bewails the complexity of the hypotheses he has to develop in order to resolve the complexities of planetary motion. Yet the comparative success and exactness with which he produced models from which the positions of the main heavenly bodies could be deduced must rank as one of the most outstanding achievements of ancient science.

Although the elaboration of the epicycle-eccentric model was the chief problem of theoretical astronomy from the time of Apollonius, a great deal of attention was also paid to purely descriptive astronomy.

[31] Ptol. *Alm.* IX.2.210.8ff.

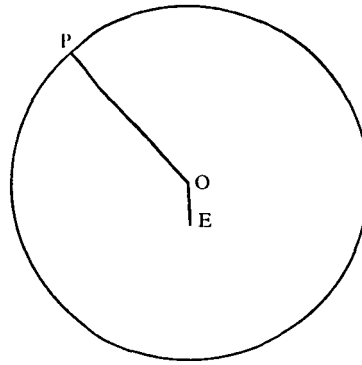

Fig. 1. Eccentric motion. The planet (P) moves round the circumference of a circle, whose centre (O) does not coincide with the earth (E). (From Lloyd 1973, fig. 6: (J 97).)

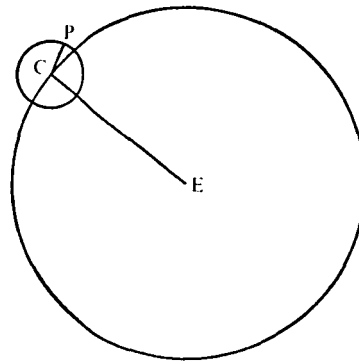

Fig. 2. Epicyclic motion. The planet (P) moves round the circumference of an epicycle, whose centre (C) itself moves round the circumference of the deferent circle, centre E, the earth. (From Lloyd 1973, fig. 5: (J 97).)

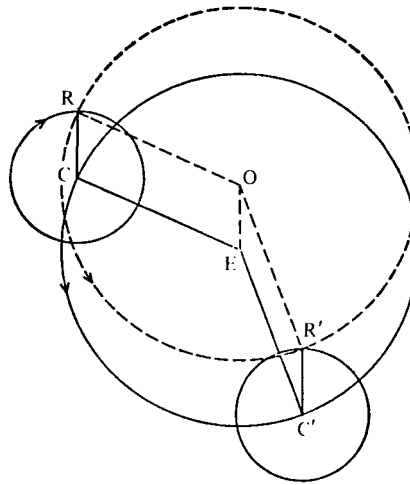

Fig. 3. The simplest case of the equivalence of eccentric and epicyclic motions. When the radius of the deferent circle (CE) is equal to that of the eccentric circle (RO) and the radius of the epicycle (RC) is equal to the eccentricity (OE), then if the angular velocities are regulated so that R and E remain the vertices of a parallelogram CROE, the two models give exactly equivalent results. (From Lloyd 1973, fig. 7: (J 97).)

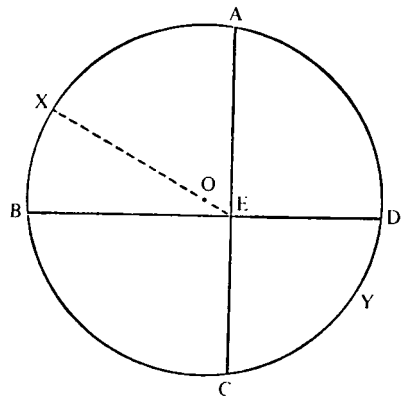

Fig. 4. The inequalities of the seasons explained by the eccentric hypothesis. If the sun moves regularly on a circle whose centre (O) does not coincide with the earth (E), it will not take the same time to traverse the four arcs AB, BC, CD and DA. X and Y are the positions of the sun at maximum, and at minimum, distance from the earth. (From Lloyd 1973, Fig. 8: (J 97).)

Already in the fourth century B.C., Eudoxus, among others, had produced accounts of the main constellations, although, since he lacked the division of the celestial globe into 360 degrees, he identified and located individual stars generally rather imprecisely. A number of specific observations made by Timocharis and Aristyllus at Alexandria around the first third of the third century were thought accurate enough to be used by Hipparchus in his astronomical theories. By Hipparchus' own time various systems of spherical co-ordinates – ecliptic, equatorial

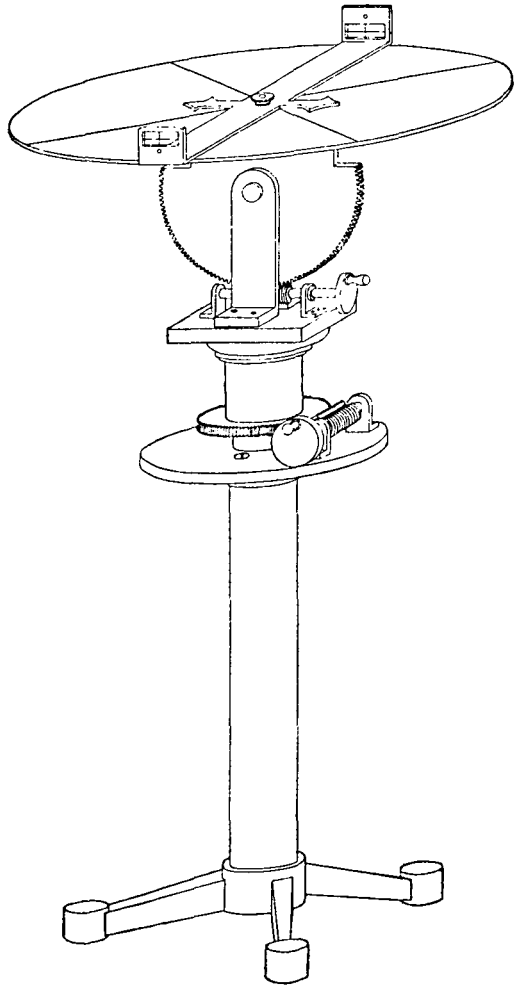

Fig. 5. Hero's dioptra, as reconstructed by H. Schöne. (From Schmidt and Schöne 1976, III.193: (J 34).)

and mixed – were employed: it was only later that the use of ecliptic co-ordinates came to predominate. Moreover, the bid for more precise observations led to certain developments in astronomical instruments. We hear of an improved dioptra named after Hipparchus, and Hero devoted a short treatise to the construction and use of the dioptra (see fig. 5), and it may be that Hipparchus also used the armillary astrolabe described at length by Ptolemy (see fig. 6).

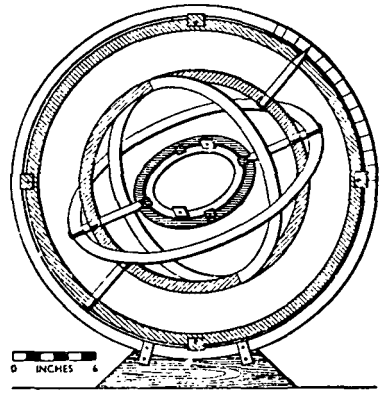

Fig. 6. The armillary astrolabe. (From *A History of Technology* III, ed. C. Singer et al. (Oxford 1957) 592.)

Hipparchus himself produced the first comprehensive star catalogue, giving the positions of an estimated 850 stars. This detailed analysis of star positions had at least one important result for theoretical astronomy, for it led Hipparchus to the discovery of the phenomenon known as the precession of the equinoxes. The positions of the equinoctial points (where the ecliptic intersects the celestial equator) do not remain constant in relation to the 'fixed' stars, but are displaced from east to west at a rate that Hipparchus estimated as at least one degree in 100 years. Ptolemy tells us how Hipparchus first thought that the shift related only to the stars near the ecliptic, only later to assure himself that it was indeed a phenomenon that applied to the fixed stars in general.[32] We are also told that he wondered whether the tropical year itself (the period defined by the return of the sun to the same solstitial or equinoctial point) may not be a constant,[33] though Ptolemy believed that he realized that the evidence suggesting that it varied was quite inconclusive, that is, that it was within the margin of error of the observations on which it was based.

[32] Ptol. *Alm.* VII.1–3.2.3ff., 3.12ff., 12.7ff., 16.15ff.
[33] Ptol. *Alm.* III.1.191.15ff.

The investigation of the problems of planetary motion was a difficult, technical and specialized matter. But two aspects of the study of the heavens commanded very general interest. One important practical motivation for astronomical observation from early times in Greece had been the regulation of the calendar. In most Greek states the beginning of the new month depended in part on observations of the moon, though these were subject to conventional, not to say sometimes quite arbitrary, interpretation by the magistrates concerned.

The second aspect relates to the belief that the stars influence or even govern human affairs. There is no good evidence that astrological prediction was practised in Greece before the fourth century, and it has been thought likely that its origin owes much to the introduction of ideas from the East. While *some* knowledge of Babylonian astronomy may go back to the fifth century, a report in Simplicius[34] suggests that more detailed information concerning Babylonian ideas became available after the conquests of Alexander, and this, if true, would relate as much to Babylonian astrological beliefs as to their more purely astronomical data – not that the Babylonians themselves would have drawn such a distinction. We should, however, distinguish between quite general assumptions that heavenly phenomena such as eclipses or the conjunctions of planets influence events on earth, and the attempt to make detailed predictions of a man's destiny from the position of the heavenly bodies at his birth. The development of astrology in the latter sense – the casting of horoscopes or genethlialogy – into a universal system owes as much to Greek elaborations (not unrelated to the development of astronomical theory) as to original Babylonian beliefs.

How extensively the casting of horoscopes or other aspects of astrology were practised in Greece in the Hellenistic period can hardly be determined, but it is probable that – as in the Middle Ages and the Renaissance – the major astronomical theorists, including Hipparchus, were also practising astrologers. Once again our best evidence comes from Ptolemy, who wrote a four-book treatise on astrology, the *Tetrabiblos*. He is under no illusions either about the distinction between, on the one hand, the attempt to predict the positions of the heavenly bodies themselves (astronomy, in our sense) and, on the other, the attempt to predict their influence on human affairs (what we call astrology), or about the difference in reliability and exactness between the two studies.[35] Astrology is uncertain and conjectural, and he adds that many current ideas on the subject are absurd. Although the determination of the positions of the heavenly bodies can be exact, the interpretation of the powers of different planets was a matter of tradition

[34] Simpl. *in Cael.* 506.11ff. [35] Ptol. *Tetrabiblos* 1.2.4.3ff.

and convention. Yet following tradition and – as it would no doubt have seemed to him – past experience, Ptolemy is prepared to try to establish a general framework for astrological predictions. There is no need to point out that the ambition to gain the ability to foresee the future must have been a powerful stimulus to many to engage, at least up to a point, in astronomical studies. Where we might be tempted to represent the relationship between what we might call the science and the pseudo-science as an entirely negative one, it is clear that the latter provided an important means of recruitment to the former.

IV. MEDICINE AND THE LIFE SCIENCES

The history of medicine and the life sciences in the Hellenistic period illustrates several of our principal themes, the increase in specialization, but also the fragmentation of scientific research, the role of royal patronage, and the patchy success in the application of scientific knowledge to practical ends. Already in the classical period those who practised medicine were clearly marked out from the natural philosophers, even though – firstly – some philosophers showed a considerable interest in medicine (Plato, even, saw fit to include a quite elaborate theory of the different causes of diseases in the *Timaeus*) and – secondly – the medical writers, for their part, varied greatly in their attitudes towards natural philosophy: some adopted or adapted much from the philosophers, especially in the matter of element theories, but others criticized the philosophers bitterly for producing untestable speculations irrelevant to the needs of the doctor faced with the task of trying to cure the sick.

In the Hellenistic period there are continuities with the various traditions represented in the Hippocratic writings, but also important developments. The continuities might well seem greater if we had more information about the work of such men as Diocles of Carystus (late fourth century) and Praxagoras of Cos (*flor. c.* 320), the latter of whom discovered the diagnostic value of the pulse and was, we are told, the teacher of Herophilus. Although none of the writings of Herophilus and Erasistratus themselves has survived, the critical reports of their work in such sources as Celsus, Rufus, Soranus and especially Galen enable us to reconstruct their ideas and interests, and the overwhelming impression we are left with is one of a high level of originality.

By comparison with either the Hippocratic writers or Aristotle, whose anatomical and physiological theories were often fanciful and naive, Herophilus and Erasistratus made massive advances in both these areas, and the principal reason for their successes lies in their use of dissection. Dissection had certainly been practised before, occasionally

by some of the Hippocratic writers, and rather more systematically by Aristotle and his school. But we can confidently say that there had been no dissection of the adult human body for scientific purposes before the Hellenistic period. The truth of the reports that Herophilus and Erasistratus not only dissected but also vivisected human beings has, to be sure, often been contested. When the Christian writer Tertullian (*c.* A.D. 200) refers to Herophilus butchering hundreds of men,[36] he is open to the suspicion of exaggeration and distortion in his eagerness to vilify Greek scientific research, even though elsewhere, at least, he draws on a reliable source, the second-century A.D. medical writer Soranus, for some of his information. But other writers tend to confirm in general terms that human dissection (at least) was practised and Celsus, in particular, provides a circumstantial report that both Herophilus and Erasistratus carried out vivisections as well on 'criminals they obtained out of prison from the kings',[37] justifying themselves against the charge of inhumanity by claiming that the good outweighed the evil.

In Herophilus' case no one doubts that this took place in Alexandria – probably in the opening decades of the third century, that is under the first two Ptolemies. So far as Erasistratus goes, if, as has recently been argued,[38] he and his pupils worked at Antioch rather than at Alexandria, then this would mean, if we accept Celsus' evidence, that there was a second centre of human dissection and vivisection in the early third century. But it may be more likely – even in the absence of other evidence confirming that Erasistratus worked at Alexandria – that the usual assumption is correct, and that the kings referred to by Celsus are the Ptolemies alone. In any event, in one if not at two cities, Hellenistic monarchs appear not merely to have permitted but to have supported biological research on human subjects.

The outcome – not just of research on humans but also of more systematic animal dissection – was some spectacular advances in anatomy and physiology. Herophilus is credited with a whole range of anatomical discoveries, and in many cases the name by which the part is still known derives from him, as our 'duodenum' from the Latin word used to translate Herophilus' **δωδεκαδάκτυλος**, a term that refers to the length of this part of the intestine in man (twelve finger's breadths) and incidentally tends to confirm his working with human subjects. More important still, Herophilus and Erasistratus jointly can be said to have discovered the nervous system, distinguishing clearly between the sensory and the motor nerves and between them and other tissues – sinews, tendons, ligaments – which had all been referred to, and indeed continued to be referred to, indiscriminately as **νεῦρα** in Greek. The way

[36] Tert. *de Anim.* 10.13.4ff. [37] Celsus, *Med.* Proem 23.21.15ff.
[38] Fraser 1969, 518ff.: (J 83); 1972, 1.347ff.: (J 84); cf. Lloyd 1975, 172ff.: (J 98).

was thus opened for the detailed investigation – such as was eventually to be undertaken by Galen in the second century A.D. – into the transmission of movement and sensation, replacing vague notions of ducts or pores connecting different parts of the body with far more definite, in some cases even experimentally established, links between nerve centres in the brain or spinal marrow on the one hand and the muscles or sense organs on the other.

Erasistratus was also responsible for developing a number of important, if sometimes highly speculative, physiological theories which Galen was later at pains to discuss, and usually to try to refute, at great length. In his theory of digestion Erasistratus emphasized the role of mechanical processes, rejecting the Aristotelian notion that digestion is the result of the action of 'innate heat'. He knew that food is propelled along the alimentary canal by the peristalsis of the gullet and the contractions of the stomach wall and he suggested that in the stomach it is subjected to further mechanical breaking down before being squeezed out as chyle into the blood-vessels. He also argued that nourishment is then absorbed by the tissues by being drawn out through the walls of the blood-vessels, a process he explained by appealing to the principle of *horror vacui*, suggesting that a partial vacuum is created in the tissues by the evacuation of certain residues and that the tissues then draw into themselves some of the contents of the blood-vessels themselves.

Even more influential was his development of an idea that is already found in some Hippocratic texts, namely that the arterial system normally contains air, not blood. Whereas several earlier writers, including Aristotle, had a fairly clear general grasp of the anatomical distinctions between arteries and veins (though they mostly continued to use the same term, **φλέψ**, indiscriminately for both types of blood-vessel), Erasistratus drew a clear physiological distinction between the two kinds of vessel. But even though the arteries, in his view, normally contain air, he supposed that in disease some blood entered from the veins, and he was evidently well aware that in lesions – when, for example, an artery is severed – blood flows from it. Here too, however, he explained these processes as the result of the creation of a partial vacuum. Blood is thereby drawn into the arteries from the veins through sub-sensible passages, **ἀναστομώσεις** or **συναναστομώσεις**, which have in common with the modern notion of capillaries that they act as communicating links between the two systems, the arterial and the venous, although in Erasistratus' theory the flow is not from arteries to veins but in the opposite direction.

Although Erasistratus also appreciated both that the heart acts as a pump and that each of the four principal valves of the heart allows material to pass through it in one direction only, he was not focussing on

the problems that later came to be resolved, by Harvey, with the notion of the circulation of the blood. Greek biologists normally assumed that whatever was pumped from the heart or came from the liver was *consumed* by the various parts of the body it reached, and for Erasistratus in particular the arterial and venous systems were, as already explained, thought of as quite distinct in the healthy subject. It is more relevant to note that the recurrent appeal to the physical principle of *horror vacui* may be one of the comparatively rare Hellenistic examples where an investigator working in the life sciences was drawing on the work of a natural philosopher. Erasistratus is associated with the school of Aristotle by some of our sources,[39] and although he is generally critical of Aristotle's own ideas, he may well have been influenced by the investigations of the vacuum which we have seen were carried out by Strato.

As our last example indicates, Erasistratus' interests included pathology as well as physiology, and so too did those of Herophilus. Both were first and foremost medical men. Herophilus, in particular, developed the theory of the diagnostic value of the pulse which he had taken over from his master Praxagoras, and produced an elaborate classification of different types of pulse according to such criteria as their 'magnitude', 'speed', 'intensity', 'rhythm' and 'evenness'. But while the medical interests of the great Hellenistic biologists may be seen as a link connecting them with their Hippocratic predecessors, the extent to which they were able to engage in anatomical and physiological research was exceptional and reflects the kind of special royal patronage and support that Celsus' report suggests.

Herophilus and Erasistratus, along with Hippocrates and many others, figure in later histories of medicine as 'Dogmatists', though this label should not be taken to imply that the individuals in question held any specific pathological doctrines in common, let alone that they were particularly doctrinaire in their medical theories. But one of Herophilus' pupils, Philinus of Cos, led a break-away not just from the teachings of Herophilus, but from any view that engaged in speculation concerning 'hidden causes', particularly those relating to the constitution of man or to the origins of diseases. Against the Dogmatists, the so-called Empiricists argued that such speculation is neither legitimate nor necessary. The doctor's task is to treat individual cases and for this purpose he must avoid theorizing and attend to, and be guided by, the manifest symptoms of the patient and these alone. Experience will teach the doctor what treatment is beneficial in particular cases. He could and should engage in the comparison of particular sets of presented

[39] See Galen, *Nat. fac.* II.4.165.7ff. Helmreich; *An in arteriis* 7.IV.729.4ff. Kühn; Diog. Laert. V.57.

symptoms, but not in inferences concerning the hidden. 'Even students of philosophy', as Celsus puts it in reporting the Empiricist view, 'would have become the greatest medical practitioners if reasoning could have made them so; but as it is, they have words in plenty, but no knowledge of healing at all.'[40]

Positively, this assertion of the incomprehensibility of the invisible went with a fruitful emphasis on medical experience and on its practical application to secure cures. But negatively it was also accompanied by the denial of the usefulness of dissection. The internal parts of man are not just normally, for contingent reasons, hidden: they are in principle not investigable. Post mortem dissection can reveal only what is true of the dead, and vivisection, involving the injury of the living, besides being cruel, is no guide to the natural state of the normal subject either.

Nor were the Empiricists alone among the Hellenistic medical sects to reject dissection. Quite when the men who called themselves Methodists first formed themselves into a separate sect is disputed, but it is clear that there was a distinct school in the first century A.D., and they traced at least some of their ideas back to Themison in the previous century. The Methodists joined the Empiricists in abstaining from the Dogmatists' investigation of hidden causes, but they also rejected the Empiricists' own assertion of the incomprehensibility of nature as itself dogmatic. Like the Pyrrhonian Sceptics, the Methodists advocated the suspension of judgement on such questions. Their medical practice was based on the notion that there are three general types of physiological/pathological condition, the 'lax', the 'tense' and the 'intermediate', though it is clear from Soranus, the chief exponent of Methodism in the second century A.D., that the interpretation of these three states was the subject of some variation and disagreement. In view of the theoretical objections that were raised, it is not surprising, perhaps, that the practice of human dissection lost ground after the time of Herophilus and Erasistratus, although it may be that a more important factor inhibiting those later anatomists, such as Rufus and Galen, who might have wished to continue the tradition, was the lack of the kind of powerful support that the first Ptolemies were able to provide.

Ancient medicine, even at its most speculative and dogmatic, acknowledged a practical end, the healing of the sick. In other areas of the life sciences the application of knowledge in practice was far more haphazard. In zoology the Hellenistic period saw little advance on Aristotle's masterpieces, though it should be emphasized that these represented a corporate effort involving his associates in the Lyceum. Aristotle's zoological treatises in turn provided the model for Theophrastus' botanical studies, the *Inquiry Concerning Plants* and the *Causes of*

[40] Celsus, *Med.* Proem 29.22.11ff.

Plants. As with Aristotle's zoology, one of the chief interests, in Theophrastus, is in the classification of plants. But it is noteworthy that his descriptions of particular species often include information about distribution, favourable habitat, diseases and usefulness to man.

One context in which what may loosely be called experimentation with the parts of plants was well established is pharmacology. Our chief literary sources, including the famous works of Dioscorides in the first century A.D., presuppose a long tradition of popular curiosity about how substances occurring naturally – not just in plants or animals, but also as minerals – might prove efficacious as remedies. On the other hand the evidence for systematic experimentation with plants in order to achieve, for example, increased crop-yields is very limited (see further below, pp. 367–9). So far as the more theoretical writers are concerned, they show a lively curiosity about such special problems as artificial fertilization – for instance of the date-palm – but do not, in general, address themselves to giving guidance on how to improve horticultural performance. The specialist writers on agriculture (including horticulture and stock-rearing), such as the Latin authors Cato, Varro and Columella, were, for their part, certainly concerned with performance, but they were essentially repositories of knowledge, and not, or not often, themselves the sources of new ideas that might be tried out in the field. In practice horticultural techniques, while generally conservative, were not immune to development, as we can see from Varro's references to the recent introduction of a new method of grafting, for instance.[41] But the advances that occurred were rather the result of trial and error at the level of practice, than the product of the application of theoretical knowledge. The theoretical knowledge that was sought was not generally of a kind that might readily be given a practical application, and here, as elsewhere, a certain lack of adjustment between theoretical interests and practical concerns can be discerned.

[41] Varro, *RR* 1.40.6.

CHAPTER 9

HELLENISTIC SCIENCE: ITS APPLICATION IN PEACE AND WAR

9*b* WAR AND SIEGECRAFT

YVON GARLAN

In the Hellenistic period, as in earlier periods, war was a presence always felt in the Greek world, not only because it happened but also because of its widespread impact upon modes of organization and expression. But clearly, we cannot possibly consider every aspect of war in a short section and shall have to confine our study here to the subject of the armies as they exercised their specifically military functions. We shall furthermore assume that the decisive changes brought about in the reigns of Philip and Alexander in this sphere are already familiar to the reader.[42]

In size the Hellenistic armies equalled those which had taken part in the conquest of the Persian kingdom. This was true at least in the kingdoms that had emerged following the break-up of Alexander's empire, although the old Greek cities usually found it hard to assemble forces comparable with those of the classical period. The sovereigns of the new kingdoms in effect went into decisive battles with about 60,000 men. Some were even in a position to raise 100,000: Antiochus III, for example, in the expedition that set out for central Asia. To these forces must be added 'those who were part of the baggage' (*aposkeue*), that is to say the heterogeneous assortment of non-combatants (women, children, slaves, merchants and entertainers of every kind) who must have swelled the numbers by an average of perhaps half as many again as the armed forces. This kind of town on the move clearly posed delicate logistic problems from the point of view of contemporary levels of productivity and means of transport, and these problems largely determined the course of military operations. The armies were incapable of sustaining themselves without any naval escort for more than four or five days so in their choice of itinerary and winter quarters they had to give top priority to the possibilities of revictualling, either through gifts or purchases more or less forced from peoples in the vicinity, or through pillage of the enemy territory. Another factor in the movement of armies was the prospect of booty which offered the soldiers their best hope of enrichment.

[42] For further reading see Bibliography, J(b).

Rather than the circulation of goods, however, it was the movement of men which was stimulated in the Hellenistic world by the formation of these large armies. In Greece itself, to be sure, military recruitment continued to rest more or less on the tradition of the soldier-citizen. It was a tradition that had become somewhat debased in several cities: in Athens, for example, the *ephebeia* took on above all the character of a cultural institution reserved for an élite. But elsewhere it was still healthy or was periodically revived when danger threatened (for example in the Aetolian or Achaean Leagues, in Rhodes, or during the third century in Boeotia, from which dozens of military catalogues have come down to us). Similarly, in Macedonia, where the aristocracy provided an officer class, the vigorous native peasantry continued to guarantee the military renown of the Antigonids despite overtures from all sides. In the newer Eastern kingdoms, however, the integration of the cream of the native forces (the Persians and Iranians) into the Graeco-Macedonian élite hardly survived the death of Alexander who had, not without causing some scandal, inaugurated the practice right at the end of his reign. Nearly all his successors and the monarchs of the early years of the Hellenistic period jibbed at such a policy, allowing native troops to serve at the very most in the naval or police forces (in Egypt) or as auxiliaries (in the Seleucid kingdom). Such monarchs were consequently compelled to draw heavily upon immigrants of Graeco-Macedonian origin, or at least of Greek culture, in order to maintain their power.

This increase in demand that was already making itself felt in the reign of Alexander had the effect of encouraging even further the phenomenon of mercenary soldiers. Inscriptions and, above all, Egyptian papyri, make it possible for us to gain some idea of the principal migratory routes in the various periods. These appear to be determined by a number of factors: at their point of origin by demographic surplus and the degree of cohesion in the community concerned, and their direction by their immediate geographical surroundings, the reputation of the employers available or the existence of political sympathies that sometimes led to the conclusion of employment agreements, similar to treaties of alliance, between one state and another. The statistical tables drawn up by M. Launey[43] reveal that 'in all the armies the proportion of Greeks, which in the third century was still considerable – being principally represented by natives of continental Greece and Cretans – decreased abruptly around 200 and virtually disappeared . . . The Balkan element, which had hitherto been quite vigorous, follows a similar downward curve although this is less steep. Asia Minor was also providing a high proportion of troops but this too progressively decreased . . . The second and first centuries, in Egypt at least, witnessed

[43] Launey 1949–50, I.103: (J 143).

a startling rise in the number of Semites.' As for the troops of Macedonian origin, once the first days of the conquest were over, the number of these serving in the East was far lower than it appears to be, since all the members of the élite corps were automatically described as Macedonian.

Some of these emigrants set out with the intention of returning as soon as possible to their own countries, but in the meantime their chief interest was to hire themselves, either in groups or individually, to employers who would at least guarantee them the best pay. Pay was broken down into a number of forms: a certain sum was paid in cash (*opsonion*, *misthos*); then there were rations of wheat and other commodities (*sitos*, *metrema*), a part or all of which might be converted into cash; special allowances for the upkeep of horses, clothing or equipment; and to this were added hand-outs of an exceptional nature and the right to revictual at cut prices in the military markets. This, together with the conditions of service, clearly made for a permanent source of conflict between the employers and the employed. It engendered a lack of discipline that sometimes degenerated into open revolts which the kings and cities involved brought to an end by concluding official agreements identical to those they made with foreign powers as, for example, the famous agreements with their respective mercenaries made by Eumenes I of Pergamum (*OGIS* 1.266) and by the Carian cities of Iasus and Theangela (Austin 33). In their daily life these uprooted men also cultivated an *esprit de corps* within associations founded upon their common native origins, membership of the same fighting unit, attendance at the same gymnasium or worship of the same god, and they liked to present the external appearance of political communities by voting honorific decrees, by dedicating statues and by celebrating sacrifices. The painted stelai of Sidon and of Demetrias in Thessaly[44] and a number of funerary epigrams suggest that some of these mercenaries were figures of considerably greater dignity than the swaggerers depicted in New Comedy and its Roman imitations, such as Plautus' Pyrgopolinices, the 'Sacker-of-fortresses', or Terence's 'Thraso-the-Brave'.

Although mercenaries were much sought after for garrison service in the cities and whenever they were needed for some decisive battle or to stir up some revolt, they nevertheless constituted a labour force too unstable and costly to be considered satisfactory. Their eastern employers therefore tried to get some of them, preferably those of Greek or Macedonian origin, to settle, so as to provide a solid and lasting basis for the recruitment of the regular forces that were needed to contain the pressure exerted by both indigenous inhabitants and other rival powers.

[44] Launey 1949–50, 1.79–81: (J 143); Plates vol., pl. 242.

To this end they were everywhere assigned parcels of land (*kleroi*) the use of which entailed military obligations, although the organization of such arrangements varied from one system to another as can be seen from the chapters of the present work that are devoted to the various Hellenistic kingdoms. We would simply make two points in this connexion: first, that these colonists were more important in the Ptolemaic kingdom than in that of the Seleucids, who were never able to avoid recruiting virtually half their forces from amongst their Asiatic allies, semi-dependents or subjects; and, secondly, that while they proved to be powerful agents of hellenization, they at the same time fulfilled their principal function increasingly badly as the years passed so that, for example, the Ptolemies were compelled to draw heavily upon the Egyptians as early as the battle of Raphia (217 B.C.) and, throughout the Hellenistic world from the second century onwards, peoples such as the Mysians, the Galatians and the Jews played an increasingly important military role. So grave was the deficiency that even the recruitment of élite troops was affected.

These élite troops initially consisted of the phalanx. In Alexander's time this was composed purely of Macedonians but those who were admitted into it thereafter were given the pseudo-ethnic title of 'Macedonian'. The essential difference between this type of phalanx and the hoplite phalanx was its use of a spear known as the 'sarissa', the length of which appears to have originally been 12 cubits (about 5·30 m). According to Polybius, it was held in both hands in an inclined position, with the base stuck into the ground (Plates vol., Pl. 101). The manipulation of this spear, which was considerably longer and heavier than the hoplite one, made it possible or necessary (according to whether one favours a socio-economic or a technical explanation) to reduce the rest of the equipment. The members of the phalanx retained a short sword for hand-to-hand fighting, a helmet and metal greaves, but all they had for a breastplate was a leather jacket and their shield was a small round one about 50 cm in diameter, often ornamented in bronze (*chalkaspides*) or in gold (*chrysaspides*). The men were arranged in battalions (comprising about 1,500 men in Alexander's time), usually sixteen rows deep, the first five of which held their spears pointing forwards beyond the first line while the remainder held them upright so that they formed a kind of anti-missile screen. To their right would be stationed the royal guard of the hypaspists, apparently with similar equipment. Some of these were sometimes called the *argyraspides* (silver shields) or constituted an élite *agema*. This entire heavy infantry, forming the pivot of the battle order, was theoretically vulnerable only to attacks from the flanks or the rear.

It was accordingly on the flanks that the most mobile and effective forces would be stationed: the peltasts, bowmen, slingers, javelin

throwers and light cavalry (frequently of local origin) and, most important, immediately to the right of the hypaspists, the heavy cavalry of 'Companions' (*hetairoi*) which gloried in the title of 'royal' and which, fictitiously at least, was described as Macedonian. To these 'Companions', who were equipped with metal helmets and breastplates, spears (shorter than those of the men of the phalanx), and a kind of scimitar, there usually fell the task of advancing in triangular formations to breach the enemy lines. Positioned in front or on the flanks would also be a number of special corps, a legacy of Eastern practice or devised by the fertile imagination of military theorists. These might include chariots of the Achaemenid type, with cutting blades attached to the wheels; camels carrying bowmen, from Arabia; soldiers equipped with oblong-shaped shields of Galatian origin; armoured horses and riders (cataphracts) on the Parthian model, and all kinds of mounted bowmen and javelin throwers often known by pseudo-ethnic names (such as the 'Tarentines'); and, most important of all, the combat elephants which were procured at great expense from India or the heart of Africa (Plates vol., pl. 110). These were used in their hundreds against enemy cavalry at the end of the fourth century B.C. (especially in the Seleucid kingdom) and thereafter with greater moderation once means had been found to diminish their effectiveness. Finally, behind the battle lines, with a purely defensive role, a number of reserve troops were positioned (used systematically for the first time, apparently, by Eumenes of Cardia) and the mass of non-combatants were encamped, the latter being the prime objective of the enemy when they broke through. The role of commander-in-chief (usually the king in person) consisted in co-ordinating the tactical deployment of the men who, in a somewhat imprecise hierarchy, were placed under his orders. To the great regret of military theorists such as Philo of Byzantium and Polybius, however, it was not long before the commander felt himself obliged to prove his 'valour' by putting himself personally at the head of his élite troops to make the decisive charge – although he would thereby often lose control of the subsequent course of the battle.

Nevertheless, the Hellenistic monarchs could not have achieved with such speed the conquests they did, had they not acquired the means to gain possession of fortified towns with the minimum of delay. On the basis of the advances already made by Dionysius of Syracuse and Philip and Alexander of Macedonia, siegecraft made spectacular progress in the fourth century, deeply impressing contemporaries and continuing to be regarded as a model for many years to come. The credit for this must go directly to the engineers who, either as professionals or for circumstantial reasons, became specialists in the construction of siege engines. Among these, for example, were the Athenian Epimachus who

in 305/4 was at the side of Demetrius (who on that occasion won the title of 'sacker-of-cities') during his siege of Rhodes, or, in the enemy camp, the Rhodian Diognetus and Callias of Aradus; the Alexandrian Ctesibius, working for Ptolemy II; Archimedes at the end of the third century, tearing himself away from his theoretical studies to devote himself to the defence of Syracuse against the Romans; Philo of Byzantium, the author of a *Mechanical Collection*, whose books relating to siegecraft have come down to us; Bito, who dedicated his *Constructions of Engines of War and Projection* to a King Attalus of Pergamum,[45] not to mention Hero of Alexandria whose dates are now thought to be in the latter half of the first century A.D.[46]

Artillery was now regarded as an essential element in siege weaponry: catapults for arrows, known as *oxybeleis*, the invention of which went back to Dionysius of Syracuse, and – from the time of Alexander's siege of Tyre in 332 – catapults for cannon balls, known as *lithoboloi* or *petroboloi*. The composite bow had been superseded by rigid arms slotted into skeins of sinews or hair under torsion. Thanks no doubt to this recent improvement in the system of propulsion, both these kinds of catapult had reached their maximum potential by the end of the fourth century B.C. They could project over a distance of slightly more than a stade (177 m) projectiles possibly as long as 4 cubits (185 cm) and weighing as much as 3 talents (78 kg). It was discovered that the performance of these machines was directly related to the diameter of the holes used to secure the propelling skein into the wooden framework and it was this that determined the dimensions of the various pieces of wood used in the composition of the catapult. It can thus be deduced that the overall measurements of a *petrobolos* of one talent (the most common kind) were 7·75 m in length, 5 m in width, and about 6·35 m in height. Around 225 B.C. Philo introduced a distinction between 'euthytones' and 'palintones',[47] possibly on the basis of the angle given to the propelling arms by the disposition of the skeins that initiated the movement. This author is also the first to mention onagers, that is *petroboloi* with a single propelling arm which only came into general use in the fourth century A.D. Finally, in the course of the Hellenistic period a number of engines that were more complex or conceived on radically different lines were brought into operation on an experimental basis – for example Dionysius of Alexandria's repeating catapult and Ctesibius' catapults operated by bronze springs and compressed air.

The action of troops hurling themselves in successive waves against the enemy positions could only be successful, however, if recourse was also had to many other methods of destruction and of approaching

[45] Cf. Marsden 1971, II.78: (J 148).
[46] Cf. *idem* 1969, I, 209: (J 148). [47] Cf. *idem* 1969, I.20–3.

walls. These, for the most part, had been invented much earlier but had never hitherto been used so systematically or on such a scale. They included mines and tunnelling; incendiary projectiles; access ramps similar to those that Alexander erected between Tyre and the mainland; wooden towers sometimes as high as 120 cubits (53 m), furnished with shooting embrasures, swing-bridges and steerable wheels, the most powerful and complex of which were given the name 'helepolis' ('the taker of towns') (Plates vol., pl. 113); large shelters for groups of soldiers, either fixed ('porches') or mobile ('tortoises'), some of which incorporated a wheeled borer or a suspended battering-ram that might measure as much as 120 cubits. There were also other innovations that enjoyed a varying success, such as the elephants known as 'wall-destroyers' which were used for the last time, apparently, by Antigonus Gonatas around 270 B.C.

The besieged would, of course, be employing similar procedures and others too that were peculiar to their position. In order to forestall or lessen the impact of the assault they adopted resolutely aggressive tactics by carrying the fighting outside the defences with numerous sorties, or by continuing it behind the main wall, and from the flanks of secondary walls built in the shape of a funnel. They countered the enemy machines with 'anti-machines' of their own that testify to the remarkable richness of their imagination. A whole gamut of these techniques is known to us, ranging from Diognetus of Rhodes tipping filth on to the path taken by Epimachus' *helepolis* to a questionable story of Archimedes setting fire to the Roman fleet by means of burning mirrors; they include the hurling of barbed tridents and body-trapping nets, the use of various scythes and grappling-irons ('crows' or 'cranes') that made it possible to shatter the frameworks of siege machines, the tipping of sand, oil or flaming missiles, and deadening the impact of projectiles by means of mattresses, screens or – on one occasion – revolving spoked wheels. In such circumstances the usual conservatism in Greek technical thought gave way under the pressure of danger – although it should be noted that most of these 'machines' still amounted to little more than stratagems and in any case did not involve the use of other than natural forces.

It is not surprising that this culmination in the development of siegecraft appears to have preceded that of the art of fortification by some decades, this being generally accepted to be the time of Philo of Byzantium (*c.* 225 B.C.). True, the second half of the fourth century B.C. already saw the invention or diffusion of devices whose purpose was obviously to counter the new techniques of attack. Flank defences were improved by 'toothed' or 'indented' fortifications, towers of various shapes (semi-circular, horseshoe-shaped, pentagonal or hexagonal), some of them large enough to accommodate artillery (Plates vol.,

pl. 114). Towers and the walks connecting them were roofed in to protect the firing positions set up there. Constructions were reinforced, for example curtain walls divided into sections by bond-stones and towers built architecturally independent of the walls. Outlying defences were improved with forecourts, trenches, outer walls and ramps. More postern gates were introduced, sometimes with low protective walls in front. But the most systematic and sophisticated devices date from the third century B.C. Particularly typical are those introduced at Apollonia in Cyrenaica, at the northern end of the acropolis of Selinus round about 270 B.C., or those of Epipolae at Syracuse, which appear to have been given their definitive form on the eve of the capture of the town by the Romans.

It is certainly no coincidence that the first Hellenistic monarchs also engaged in naval construction on a gigantic scale. The largest warships were admittedly in a minority among the two or three hundred vessels at the disposal of Demetrius and the first two Ptolemies, which did not include the transport ships for troops, horses and provisions and light craft of many kinds. But on the largest warships the number of 'rows' of oarsmen, which had not exceeded four or five in Alexander's time, was progressively increased first, with Demetrius, to sixteen, then with Antigonus Gonatas to eighteen and, under Ptolemy II, first to twenty

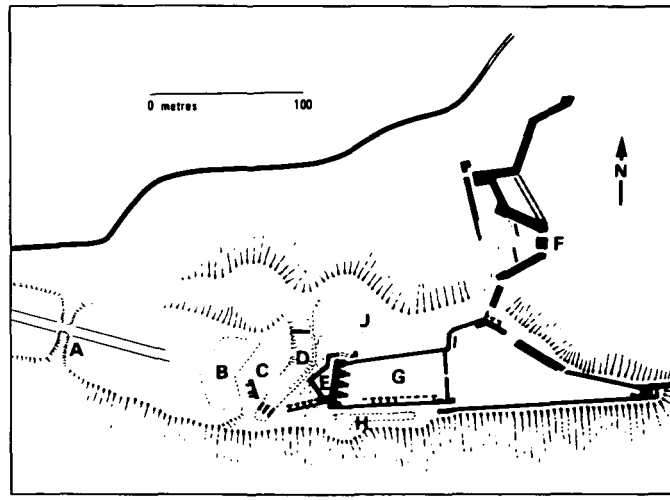

Fig. 7. Plan of the fort of Euryalus

Key

A Ditch
B Ditch
C Outwork
D Ditch
E Bastion
F Epipolae gateway
G Keep with five towers on western side
H Ditch

(After A. Macadam, *Sicily* (Blue Guide, London 1981) 151.)

and then to thirty. The culmination was reached with forty rows, on a vessel built purely as a showpiece by Ptolemy IV, which could accommodate 4,000 oarsmen as well as 400 other sailors and nearly 3,000 soldiers. It is a startling increase and can only have been achieved by introducing superimposed layers of benches (three at the maximum) and increasing the number of oarsmen to each oar (eight at the maximum): with more than 24 rows this would imply a vessel with two hulls, like a catamaran. But, from the end of the third century B.C., this form of competition, which must have reduced naval warfare to a confrontation between floating fortresses, died away, and more modest designs came back into favour. Thus the Rhodian fleet, which ruled the seas in the second century B.C., was essentially composed of quadriremes and triremes or even lighter craft such as *trihemioliai* which were well suited for fighting pirates.

Greece itself, both through attachment to its glorious past and no doubt through lack of material means as well, introduced hardly any military innovations during this period. Certain specialized skills were maintained, however: the bow in Crete and wherever Greeks and barbarians were in contact with one another, the sling in Achaea and Rhodes, the javelin in the Balkans . . . and the art of generalship in Sparta. Infantry of the line remained in general composed of hoplites and peltasts, with their characteristic equipment tending to become confused since the former now sported only a light or half-breastplate while the latter had in some cases exchanged their *pelte* for a Galatian *thyreos*. And it was only very late in the day that a number of cities, in the hope of finding victory once again, decided to yield to contemporary taste and adopt a panoply of the Macedonian type: the Boeotians in 250–245, Sparta in the reign of Cleomenes III and, to some extent, the Achaeans in the time of Philopoemen.

Apart from the archaic and decrepit nature of most of the citizen armies, it is the fossilization of the military art in the Hellenistic kingdoms that, from a strictly technical point of view, chiefly accounts for the difficulties they encountered when faced with Parthian horsemen in the East and the victorious Roman legions. It is a decline that should also, no doubt, be imputed to the dwindling of the treasures to be won in war, and to the increasingly inferior sources of recruitment, and also to the obsession with civil or dynastic wars that set the Greek states one against another. These factors account for the persistent mediocrity in military encampments which Polybius laments, for the reduction in initiatives taken both in siegecraft and in naval warfare and also for a diminishing manoeuvrability in pitched battles. The impressive – all too impressive – mathematical requirements assigned, with hindsight, to the Macedonian phalanx by the theoretician Asclepiodotus, who was a

disciple of Posidonius, could not in practice counter the major criticism levelled at it by Polybius, who was a connoisseur of such matters: namely, that the phalanx disintegrated once contact was made with the enemy, especially on uneven ground (XVIII.28–32). The early users of the phalanx had sometimes sought to render it more manoeuvrable (Alexander the Great by replacing the central ranks by lightly-armed troops; and Pyrrhus, against the Romans, by arranging it in battalions that were interspersed with more mobile contingents). Nevertheless, its rigidity subsequently did nothing but increase, with the adoption of the longer sarissa spears (12 to 14 or even 16 cubits in length) and the battle formation of serried ranks (*synaspismos*). Meanwhile the cavalry, which had to varying degrees also become heavier, was proportionally less numerous than hitherto and was therefore incapable, as was the light infantry, of making any decisive impact (with the probable exception of that of the Bactrian kingdoms which were obliged to adapt to the modes of combat employed by the inhabitants of the steppes). The head-on assault of the phalanxes thus became crucial. Correspondingly, the art of generalship degenerated into stereotyped formulae. As for their encampments and their discipline, here too the Greeks were far inferior to the Romans. They were nevertheless reluctant to learn from their conquerors. There were only three partial exceptions to this: Philip V, from whom two sets of military regulations have survived, testifying to some effort at adaptation; Antiochus IV, who, at the review at Daphne in 165 B.C., produced 5,000 men 'equipped in the Roman style with coats of mail' (Polybius XXX.25.3); and Mithridates Eupator, who ended up by experimenting with the tactics of the maniple.

The Hellenistic states had their origins on the battle-field and that is where they met their doom. This outcome was not surprising and was altogether in line with the determining role played by violence in such societies.

CHAPTER 9

HELLENISTIC SCIENCE: ITS APPLICATION IN PEACE AND WAR

9c AGRICULTURE

DOROTHY J. THOMPSON

Agriculture had always been, and was to remain, the basis of the ancient economy. The aim of this section is to consider the effect on agriculture of the very changed political, social and cultural conditions which followed Alexander's conquest of the East. In the new political world of Hellenistic kings and inter-connected Greek cities, in the context of royal patronage encouraging experimentation and the production of scientific and technical literature, how far were actual agricultural practices either developed or modified? What were the effects on agriculture of the changes in land-tenure brought by the arrival of new settlers? As so often, answers can only be partial, provisional and impressionistic. Egypt is the only country for which the surviving documents allow a more thorough investigation and here the pattern of irrigation-agriculture was always peculiar to the Nile valley, geographically and climatically divorced from the rest of the Mediterranean basin or the Hellenistic kingdoms of the East.

One of the most striking features of this period is the growth of scientific and practical manuals. When in 37 B.C., at the end of a productive literary life, the Roman writer Varro published his *de re rustica* he introduced his work (1.1.8–10) with a list of his predecessors and sources, more than fifty of them. His Latin predecessors, the two Sasernae and Cato, are mentioned later (1.2.22 and 28) and in an otherwise Greek context pride of place is here ascribed to the Carthaginian Mago, whose Punic handbook in twenty-eight books was translated into Greek and condensed into eight of the twenty books of Cassius Dionysius of Utica. Apart from this study, further usefully abridged to six books by Diophanes of Galatia, Varro lists forty-nine Greek experts (including the poets Hesiod and Menecrates of Ephesus), two of whom are kings, five described as philosophers, and of the others five are from Athens, three from the North Aegean coast, ten from Asia Minor and six from the larger Aegean islands; others are listed by name only. The Hellenistic legacy to Rome is inescapable and, whilst the listing of literary predecessors is conventional and unlikely to be either original or even to record Varro's direct sources, its very existence and the widespread origins of those included illustrate the extensive interest

in agriculture which characterized the period. The surviving literature which may broadly be called agricultural falls into two main categories. These are the scientific studies of Theophrastus, his investigations into botany and his study of plants, in which practical knowledge and observation are subordinated to a botanical classification, and the more practical manuals in which agricultural processes are described and advice given on a wide variety of country matters. Theophrastus was well aware of matters of practical agriculture, of the importance of manuring, for instance, or of the careful selection of seed corn,[48] but Varro's view that such scientific studies were more suited to those attending schools of philosophy than to those tilling the soil[49] was probably widely shared by practising farmers. In the *Georgica* of the Egyptian Bolus, on the other hand, practical advice on a wide range of subjects (times for planting and harvest, arboriculture, market gardening) was mixed with folklore.[50] Archibius' advice to Antiochus, king of Syria, on how to prevent storm damage to crops by burying a toad in an earthenware pot in the middle of the field[51] was one sort of advice interspersed in these manuals. Such treatises together with those on viticulture and apiculture[52] may be assumed, from the more strictly practical nature of their contents, to have had a wide circulation, if not influence.

The Hellenistic world was a world of kings and, just as earlier Persian rulers had interested themselves in the agricultural development of their kingdoms,[53] so their Hellenistic successors showed similar concerns. Kings might sponsor scholarship or they might sponsor actual agricultural experiment. Active in both areas, in neither were they alone. Manuals might be written without royal patronage, others besides kings might attempt improvement of crops and livestock. It is not known, for instance, whether Bolus of Mendes wrote his *Georgica* around 200 B.C. under sponsorship, though had this been the case he might not have needed to take the pseudonym Democritus, a name assumed in a (partially successful) attempt to identify himself with the earlier and better known natural philosopher of Abdera. Innovation in agriculture was also possible apart from royal sponsorship, as for example in the planting of vines in Susis and Babylon introduced on a large scale by the Greek settlers there.[54] Yet interest in agriculture, that is in the economic basis of their new kingdoms, is a widely-documented feature of

[48] *Hist. Pl.* VIII.7.7.; 11.5; *Caus. Pl.* IV.3.4. Jardé 1925, 14: (J 162).

[49] *RR* I.5.1–2. [50] Wellman 1921, 42–58: (J 168).

[51] Pliny, *NH* XVIII.294.

[52] Rostovtzeff 1953, III.1618 n.144 and 1619 n. 148: (A 52), for bibliography. On *PSI* 624= *P. Lugd. Bat.* XX.62 see Cadell 1969: (J 157).

[53] E.g. *SIG* 22.

[54] Strabo XV.3.11.C.731–2, modified by Rostovtzeff 1953, 1164–5: (A 52).

Hellenistic kings. Hiero II of Sicily and Attalus III Philometor of Pergamum head the list of Varro's experts and Attalus himself is mentioned elsewhere as the author of a work on plants and gardens; Diophanes sent his study to King Deiotarus of Galatia and Archibius addressed agricultural advice to Antiochus, king of Syria.[55] Theophrastus was approached by Ptolemy I Soter and his works were purchased by Ptolemy II Philadelphus for the Library at Alexandria.[56]

Besides their literary sponsorship Hellenistic kings played an active part in encouraging agricultural development and innovation. Alexander had shown interest both in the draining of Lake Copais in Boeotia and in the irrigation system of Babylon.[57] In Egypt large-scale reclamation projects in the Fayyûm, recorded both in the papyri and from archaeological excavation, as much as trebled land under cultivation in the area.[58] The Ptolemies' interest also in the techniques of improved cultivation is reflected in the appeal to the king of a Greek soldier settled in the Thebaid in the third century B.C. to support his demonstration of a water-raising machine which would counteract the effects of the recent drought: 'with its help the country-side will be saved . . . within fifty days of the time of sowing there will immediately follow a plentiful harvest throughout the whole Thebaid'.[59] The device mentioned here may be the sakia, the Persian wheel, which joined the long-established bucket-and-pole shadoof in making possible the cultivation of land irrigated perennially.[60] The Archimedes screw was also introduced in this period, bringing abundant harvests in the Delta.[61] Land reclamation and the techniques of improved agriculture were both the concern of Hellenistic kings.

Royal interest may also be charted in a variety of innovations, both in animal husbandry and in agriculture proper. As earlier Polycrates of Samos had attempted to improve livestock in his kingdom,[62] so Hellenistic kings experimented in stockbreeding. The notable strains of cows and sheep produced in Epirus by Pyrrhus in the fourth century were known by his name,[63] and in Egypt, under Ptolemy Philadelphus, Milesian and Arabian sheep were introduced to the Fayyûm on the 2,500 ha. gift-estate of his *dioiketes* Apollonius.[64] Philetaerus, perhaps typical of the Attalid kings, showed an interest in pasturage and

[55] Varro, *RR* I.1.8; Pliny, *NH* XVIII.22 (also Archelaus) and 294.

[56] Diog. Laert. V.37; Athen. I.3b.

[57] Strabo IX.2.18.C.407 (cf. Diog. Laert. IV.23 (for Crates); XVI.1.9–11.C.740–1.

[58] Butzer 1976, 47: (J 156). [59] *P. Edfou* 8.

[60] *P. Cornell* 5. On irrigation techniques: Crawford 1971, 107: (J 158).

[61] Diod. I.34.2; see above, p. 336; Plates vol., pl. 260.

[62] Ath. XII.540c–d, hunting-dogs from Epirus, goats from Scyros, sheep from Miletus, pigs from Sicily.

[63] Arist. *HA* III.21, 522b24–5; VIII.7, 595b19 (early interpolations); Pliny, *NH* VIII.176.

[64] *P. Cairo Zen.* 59195.3; cf. 59430.

stockbreeding in his kingdom[65] and the three hundred or more Lycaonian flocks of Amyntas, the last ruler of Galatia, were well known as a source of his wealth;[66] it is disappointing that Strabo has not preserved more detail on the nature and size of these flocks. Some royal experiments, such as the imported and exotic pheasants and guinea fowl reared in the palace at Alexandria for the court of Ptolemy VIII Euergetes II, might be of very limited importance,[67] but the new cultural unity of the Hellenistic world combined with royal initiative to make possible the spread of improved plants and animals within this world.

Most of the information on plants is again from Egypt where an archive from Philadelphia in the Fayyûm, the papers of Zenon, manager of the gift-estate of the *dioiketes* Apollonius, gives a detailed picture of intensive agricultural activity in the mid third century B.C.[68] The Fayyûm, or Arsinoite nome, was the centre of Ptolemaic reclamation and experimentation. There were new owners to cultivate this land, Greek soldiers settled as cleruchs in the countryside (in an attempt both to reward them and to tie them to their new homes) and the recipients of gift-estates such as Apollonius. This change in the pattern of Egyptian land-tenure had important agricultural consequences, at least at the outset. As in Babylonia, Greek settlers in Egypt brought new crop strains or made changes to the balance of traditional agriculture. Land brought under cultivation for the first time was planted with new crops and orchards. A wide variety of crops is recorded, for example oil crops on marginal lands at the edge of the irrigated area where salinity from poor drainage remained a problem despite the extended canal system. Such crops, however, whilst serving an agricultural purpose, might also be planted for fiscal gain. In 259 B.C. Apollonius was himself responsible for a lengthy decree on the organization of both the cultivation and taxation of the major oil crops: sesame, castor-oil (*kroton* for *kiki*-oil), *kolokynthos* (gourds), safflower and flax.[69] How effective this decree may have been in monitoring oil production is open to dispute but it attests both royal interest and interference in agriculture. The emphasis on oil production is short-lived and the widespread cultivation of cash crops seems to have been contrary to the traditional practices of Egyptian agriculture.[70] Other innovations in the Fayyûm had a longer life. Vines and olives (not covered by the Revenue Laws) were planted extensively in the area, remaining through into the Roman period,[71] and the royal garden of the palace at Memphis served as a nursery for the young trees and seedlings to be transplanted in the neighbouring Fayyûm: figs, walnuts, peaches, plums and possibly apricots.[72] Plants came to Egypt

[65] *OGIS* 748.
[66] Strabo XII.6.1.C.568.
[67] Ath. XIV.654C from Media.
[68] Rostovtzeff 1922: (J 164); Préaux 1947: (F 141).
[69] *P. Rev.* See above, pp. 148–9.
[70] Crawford 1973, 249–50: (J 159).
[71] Strabo XVII.1.35.C.809.
[72] Préaux 1947, 26–7: (F 141), for detailed references.

from all over the Hellenistic world: garlic from Tlos in Lycia,[73] chick-peas from Byzantium,[74] the cystus from Carmania,[75] figs from Chios and Syria,[76] wheat from Calymnos.[77] Diphilus of Siphnos describes an unsuccessful attempt to improve the quality of the Egyptian cabbage which was somewhat bitter to Greek taste.[78] Seed was brought in from Rhodes to Alexandria and for a year the quality of the vegetable improved; the bitterness then returned, thereby illustrating the common belief that within three years seeds would acquire the native characteristics of their new home.[79]

The Zenon papyrus archive is full of enquiries, proposals and reports on agricultural matters (Plates vol., pl. 119). The influx of Greeks to the new city of Alexandria and as military settlers in the countryside meant new demands and markets; Apollonius' estate was one of the areas where attempts were made to satisfy them. It is reminiscent of the attempts of Harpalus in Babylon to introduce a familiar flora to the area.[80] But in considering the evidence from Apollonius' 10,000 aroura (2,500 ha.) estate two points must be made. Firstly, there is the exceptional and short-lived nature of the whole experiment. There is no evidence that as a unified and organized agricultural concern the estate survived the third century; the extreme experimentation and agricultural activity may not even have outlasted Zenon who, on losing his post in 248–247 B.C., devoted himself to viticulture in the area.[81] Secondly, even within the estate there is evidence for only a limited interest and concern for the new commercial crops. Letters dealing with seed purchases and enquiries about new crops are almost entirely confined to those whose Greek names at this date probably still suggest an immigrant origin. Apollonius, Zenon and their Greek and Carian friends were only a small group within a more traditional peasant population and in some matters they might lack the respect and co-operation of the Egyptian peasants. Some Heliopolitan peasants for instance, newly settled in the Fayyûm, complain to Apollonius in 257 B.C. that 'a large number of mistakes have been made in the 10,000 arouras since there is no one experienced in agriculture'.[82] The organization of agriculture, the conditions of land-tenure and the identity of the cultivators are all important factors in the impact of agricultural innovation.

[73] *PSI* 433 = *P. Cairo Zen.* 59299 (250 B.C.); *PSI* 332 (257 B.C.).
[74] *P. Cairo Zen.* 59731 = *P. Col. Zen.* 69.14, 16, 21.
[75] Pliny, *NH* XII.76 (frutex).
[76] *P. Cairo Zen.* 59033.12; cf. 59839.6–8, Laconian and Libyan figs; *PSI* 499.6; 1313.10.
[77] *Etym. Magn.* 486.25 *s.v.* Κάλυμνος. [78] Ath. IX.369ff.
[79] Theophr. *Hist. Pl.* VIII.8.1; *Caus. Pl.* I.9.2.
[80] Theophr. *Hist. Pl.* IV.4.1; Pliny, *NH* XVI.144.
[81] *P. Cairo Zen.* 59832.4; *PSI* 439 (244 B.C.). The estate reverted to the crown before 243 B.C., Edgar in *P. Mich. Zen.* I. pp. 6–7. [82] *P. London* VII 1954, 7–8.

It was not the new cash crops which the peasants chose to cultivate in their fields. A mid third-century B.C. papyrus from the north-west Fayyûm gives details for four villages of the annual crop order which was drawn up to check centrally the pattern of agriculture throughout the country.[83] Figures are given for the distribution of crops which have in fact been sown in contravention of the order together with official adjustments made to the original demands in the light of the present state of cultivation. The crops which had not been sown were the commercial oil crops, flax, safflower and poppy; in preference the peasants had planted subsistence crops, cereals (wheat, barley and *olyra*) and vetch for fodder. The evidence from land surveys of the end of the second century B.C. from the south Fayyûm village of Kerkeosiris shows a similar range of traditional subsistence crops. On the cultivated crown land between 121 and 110 B.C. wheat, barley and *olyra* accounted annually for between 57% and 65% of the area cultivated; lentils accounted for 13% to 20% and beans, garlic, black cummin, fenugreek, arakos, grass, pasturage and fodder crops made up the rest in varying quantities.[84] In spite of a fairly large settlement of military cleruchs in the area (accounting for 33% of the village land) this pattern of cultivation, with cereals and fodder crops predominating, was a traditional one and is more likely to be typical of the general agricultural picture of the country than is Apollonius' third-century gift-estate. Unless the peasants' preferences coincided with royal interests, agricultural experimentation was likely to be short-lived.

The one innovation in Egypt to which this combination of interests can be seen to apply is the acceptance of new wheat strains. Under Philadelphus attempts were made to increase cereal production by the introduction of a second crop of summer wheat, probably einkorn. During the third century Eratosthenes commented on summer and winter sowing in both India and Arabia[85] and in late December 256 B.C. a papyrus records instructions sent by Apollonius to Zenon to sow a three-month wheat on land irrigated artificially.[86] The wheat concerned may perhaps be identified with Syrian wheat, first recorded in Egypt in this period,[87] though this was only one of a wide variety of wheats grown on Apollonius' estate.[88] The practice of double-cropping is not recorded beyond the third century but the change of the main cereal grain in Ptolemaic Egypt from husked emmer wheat, *Triticum dicoccum*, the *olyra* recorded by Herodotus (II.77.3–5) as the staple crop of the country, to a

[83] *SB* 4369 a–b with Vidal-Naquet 1967, 25–36: (J 167).
[84] Crawford 1971, table XIII: (J 158). [85] Strabo XV.1.20.C.693; XVI.4.2.C.768.
[86] *P. Cairo Zen.* 59155. [87] Thompson 1930: (J 166).
[88] Persian wheat: *P. Ryl.* IV.571.4; native and dark summer wheat; *P. Cairo Zen.* 59731 = *P. Col. Zen.* 69.25–6.

naked tetraploid wheat, *Triticum durum*, was both popular and almost total. Within a hundred and fifty years *olyra*-cultivation had declined dramatically;[89] *Triticum durum* was, with barley, grown throughout the country and used for official rations, as the normal bread-flour and for export. Such a successful and far-reaching innovation as the replacement of the staple bread cereal could only take place in conditions in which royal interest (a fiscal concern for the country's main product for export) and the peasants' preferences combined.

Most of the agricultural change introduced in the Hellenistic world was internal to that world; the introduction of new species was often from countries in close political contact. Democritus Bolus of Mendes mentions the pistachio bush, recorded by Theophrastus in Bactria[90] and by Posidonius in Syria,[91] as grown in Egypt in his day,[92] and in the first century Paxamus was the first to describe in detail its cultivation in Greece.[93] But if the pistachio travelled from Syria to Egypt the Egyptian bean and lentil made the reverse journey.[94] Ptolemaic control of the area may have been the context in which these transfers took place. There is also, however, some evidence for the introduction of species from outside the Greek-speaking world. Alexander's expedition had opened up the spice trade from the East. Both the Ptolemies and the Seleucids attempted to acclimatize the frankincense tree to their countries and Seleucus I to grow cinnamon in Syria.[95] None of these experiments met with long-term success and their interest lies mainly in illustrating the far-reaching concerns of Hellenistic kings.

With Alexander's conquests a new world had been opened up to Greeks; Greek cities, settlers and kings might all provide a stimulus for change. New patterns of land-holding, whether military cleruchies or gift-estates, such as that of Apollonius at Philadelphia or Mnesimachus near Sardis, might affect the patterns of agriculture.[96] Some reclamation took place, there were improvements in irrigation techniques, as in the construction of wine- and olive-presses, and in Egypt, with the limited adoption of metal for plough-shares and some other tools,[97] some marginal improvement was made in agricultural implements. Writers such as Pliny record the introduction of new and exotic plants; the Zenon archive from third-century Egypt shows intensive agricultural

[89] Schnebel 1925, 94–9: (J 165). On the grains see Moritz 1958, xxii–xxv: (J 163).

[90] *Hist. Pl.*, IV.4.7. [91] Ath. XIV.649d.

[92] Wellmann 1921, 19: (J 168); Rostovtzeff 1953, III.1609 n. 98: (A 52), suggests an early Seleucid introduction to Syria.

[93] *Geop.* X.12.3.

[94] Heichelheim 1938, 130: (J 161).

[95] Pliny, *NH* XII.56–7; XVI.135.

[96] Buckler and Robinson 1932, no. 1: (B 56).

[97] *P. Cairo Zen.* 59782a; 59849; 59851; *PSI* 595, confined to Apollonius' estate and not found in excavation.

activity in one (rather exceptional) area of the country. But innovation is more notable, more likely to attract record than is no change, and for Egypt at least there is evidence showing a more traditional picture of agriculture in regular use. Although quantification is impossible, there was probably minimal change in the Hellenistic countryside. The constraints of climate and of the traditional attitudes of the peasants were strong. Without a change in these, significant and lasting changes in agriculture were unlikely to occur.

CHAPTER 9

HELLENISTIC SCIENCE: ITS APPLICATION IN PEACE AND WAR

9*d* BUILDING AND TOWNPLANNING

F. E. WINTER

In various forms the Hellenistic architectural tradition flourished over a very wide area, and many Hellenistic buildings and complexes survived relatively intact through later antiquity. Thus extant Hellenistic structures far outnumber those of earlier Greek periods; moreover, the body of known material is constantly growing as a result of new discoveries. Nevertheless, Hellenistic architectural chronology is often imprecise. In the Syro-Palestinian region few major monuments are firmly dated before the first century B.C.; and in Egypt, apart from a few important temple-complexes, and a series of Alexandrian tombs commencing not later than 300,[98] the record is fragmentary, and many dates uncertain. Students must therefore rely mainly on evidence from Greece, the Aegean and Western Anatolia, and on the Italo-Hellenistic style that flourished west of the Adriatic. The Western monuments are also important for their influence on Rome, and through Rome on the Italian Renaissance.

(a) *Hellenistic townplanning*

From the second quarter of the fourth century onward kings and local dynasts of the Eastern Mediterranean founded an unprecedented number of new cities with grid-plans of classical Hippodamian type.[99] Since urban traffic consisted mostly of pedestrians and pack-animals, ancient cities, regardless of terrain, required few main thoroughfares for wheeled traffic, and secondary lanes could be sloping ramps, or even stepped. Regular grids, however, facilitated both 'zoning' and division into blocks of uniform size and shape,[100] and thus occur in the vast majority of classical and Hellenistic foundations.[101]

[98] Plates vol., pl. 254.

[99] See Tcherikower 1927: (A 60); Martin 1974, 163–76: (J 231); Bean 1971, 135–52 (Cnidus), 101–14 (Halicarnassus): (J 179), both promoted by the Hecatomnid dynasts of Caria; Downey 1961, 70–1: (E 157); *Ancient Antioch* (Princeton, 1963) 28, on early Seleucid foundations in Syria. On Hippodamus, Arist. *Pol.* II. 1267b, Hsch. *Lexicon s.v.* *Ἱπποδάμου νέμησις.*

[100] Arist. *Pol.* II, 1267b34–8; Martin 1974, 104–6: (J 231).

[101] See plans in Martin 1974: (J 231) and Ward-Perkins 1974: (J 256), Plates vol., pls. 47, 68.

Such plans were very convenient for the inhabitants, but had virtually no 'open spaces'. Moreover, the generally windowless façades flanking the long straight streets must have been quite monotonous. Slight changes in alignment of the grid provided little relief, being designed simply to avoid obstacles or help in circumventing excessively steep inclines.[102] Impressive architectural vistas did occur, but were generally confined to agoras and major sanctuaries; yet the backdrop of mountains, or sea, and sky lent interest to many townscapes (Plates vol., pls. 58, 64).

Radical departures from a uniformly oriented grid were rare. Ancient references to 'theatre-like' plans indicate, not a radial street-plan, but rather the relationship of a central agora, or agora and harbour (the 'orchestra' of the theatre), to the surrounding area (the auditorium). However, some changes in the grid may have occurred as the streets bent around the flanks of a harbour, e.g. at Halicarnassus.[103]

Even on sloping ground, as at Priene and Alinda, the Hellenistic agora was usually rectangular, with stoas on all four sides. Pergamon (Upper Agora) and Assus are notable exceptions; and the agora at Morgantina in Sicily was divided into two terraces connected by imposing stairways.[104]

There were apparently several regional schools of Hellenistic townplanning. For example, a series of known, or partly known, early Seleucid plans may indicate a theoretical model for complete settlements, with blocks of uniform size within an overall area of 220 to 250 ha.[105] In Pergamene cities the necessity of planning, or remodelling, settlements on irregular terrain encouraged effective integration of architecture and landscape. While the special character of Pergamum itself resulted largely from converting a military stronghold into a royal capital, the various elements were so skilfully fitted into the natural contours of the site, that the ensemble, even in ruins, remains extraordinarily impressive.[106]

(b) *Hellenistic building materials and techniques*

Perhaps the most significant development of the Italo-Hellenistic style of the Western Mediterranean was the replacement of fitted stone-

[102] E.g. at Selinus (Ward-Perkins 1974, fig. 31: (J 256)), Piraeus (Lenschau, *PW* XIX.1 (1938) 81–2, plan II), Olynthus (Martin 1974, 111, fig. 9: (J 231)), Cnidus (Martin 1974, pl. 31). At Miletus the slight change in orientation of the main N.–S. street south of South Agora was probably due to the location of the pre-existing Sacred Gate and Road.

[103] Vitr. *De Arch.* II.8.11 clearly uses the term 'theatre-like' of the *site*, rather than the street-grid, of Halicarnassus; and the Hippodamian grid of Rhodes (Kontis 1958: (J 221)) shows that Diod. XIX.45.3 must be interpreted in the same manner.

[104] Plates vol., pl. 97.

[105] Sauvaget 1934, esp. 108–9, fig. 11: (J 246), and 1941: (J 247) (Aleppo), 1949: (J 248) (Damascus); Downey 1961: (E 157) (Antioch and Laodicea); Balty 1969: (E 151) on Apamea.

[106] Cf. the similar effects at the Pergamene sites of Assus (Clarke *et al.* 1902–21: (J 194)) and Aegae (Bohn 1889: (J 185)). See Plates vol., pl. 58.

masonry[107] by various forms of mortarwork. Earlier Greek examples of stucco facings and of rubble masonry set in clay mortar, though more durable than mudbrick, and cheaper than ashlar, trapezoidal or polygonal masonry, were quite inferior to the genuine mortarwork developed in Italy, i.e. walls with a concrete core, consisting of a mixture of aggregate (*caementa* in Latin) with mortar, between facings of stone or baked brick set in mortar.

East of the Adriatic true mortared masonry was unknown before the later fourth century; perhaps Graeco-Macedonian architects were encouraged to experiment with this technique by encounters with actual examples during Alexander's Near Eastern campaigns.[108] Yet the use of mortarwork spread slowly among the Greeks, even in South Italy and Sicily, and was never really common in Hellenistic building.[109] Probably walls and columns constructed of soft stone and finished in stucco were equally convenient;[110] and Greek columnar façades in any event required massive stone beams above the columns.[111] Only when Greek post-and-lintel systems were replaced by Roman arches and vaults could mortarwork be used throughout entire buildings.

Alexander's eastern campaigns were probably also responsible for the introduction in Hellenistic architecture of true arch and vault construction, which appears after *c.* 325 in many contexts all over the Aegean.[112] West of the Adriatic the arch probably came into use even earlier. Here too it was doubtless imported; but on balance the evidence is against transmission from the Near East via the Aegean to Italy.[113]

Corbel arches and vaults had been familiar in Greece since Mycenaean times, but no pre-Hellenistic Greek examples rival the Lion Gate and the Treasury of Atreus at Mycenae. The great corbelled gateway at Assus, however, is quite as imposing as anything Mycenaean;[114] and Hellenistic combinations of voussoirs and corbelling are more sophisticated than any earlier Greek structures.[115] Yet Hellenistic architects apparently never considered seriously the merits of vaulted construction in

[107] See Plates vol., pls. 81, 114–16.

[108] Arrian (*Anab.* II.21.4) records that the walls confronting Alexander at Tyre in 332 were 'built of large stones laid in gypsum mortar'.

[109] Over a century after Alexander, Philo of Byzantium still recommends mortar only for facings, not for the fill (Philo 80.7–8, 81.6–8; cf. Winter 1971, 136: (J 259)).

[110] See Plates vol., pl. 67.

[111] See Plates vol., pls. 50, 54, 59, 86–7.

[112] See Boyd 1978: (J 188); Plates vol., pls. 71, 85, 115, 141.

[113] *Pace* Orlandos 1968, II.236: (J 237), and Napoli, 1966, 217–20: (J 234).

[114] See Plates vol., pl. 116; Winter 1971, 252, fig. 282: (J 259); Akurgal 1978, pl. 30a: (J 170); pre-Hellenistic according to A. W. Lawrence, in J. M. Cook, *The Troad* (Oxford 1973) 242–5. For a corbelled relieving arch, still standing in 1845 over the main gate of Assus, see Conybeare and Howson, *Life and Epistles of St Paul* II (London, 1881) 215 fig. and n. 1.

[115] E.g. the combination of corbel and keystone described by Philo of Byzantium (87.37–47); cf. Diels and Schramm 1919 (1920), 44 fig. 23: (J 27).

mortarwork,[116] or of arches framed by engaged columns (or pilasters) with horizontal entablature.[117]

While mudbrick construction occurs in all periods of Greek architecture, baked bricks are usually associated with Roman work. Yet here too there were some Hellenistic experiments, again perhaps inspired by firsthand experience of Near Eastern examples.[118]

In classical times free spans of slightly over 10–11 m, for example in the nave of the Parthenon, were doubtless near the maximum considered safe for wooden beams. Longer spans would have required triangular trusses, which were clearly still unknown *c.* 340, when Philo of Eleusis designed the new Piraeus arsenal (see fig. 8).[119] After *c.* 250 trusses must have been used in the porches of the Sardis temple and in the covered halls at Priene, Miletus, and perhaps Notium, for spans ranging from about 14 to (possibly) 20 m.[120] Yet Eastern Hellenistic builders never equalled the achievement of their Italo-Hellenistic counterparts, who, by the end of the first century B.C., routinely bridged spans up to 25 m.

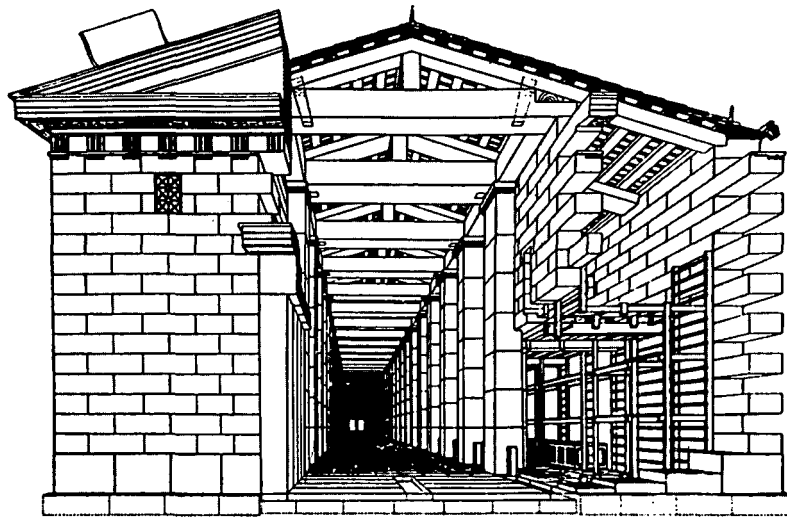

Fig. 8. Restoration of Philo's arsenal, Piraeus. (From Lawrence 1973, fig. 147: (J 224).)

[116] The cement vault of Upper Pirene on Acrocorinth, plausibly dated before 146, is quite unusual; see *Corinth* III.1 (1930) 31–44.

[117] Arched façades of *c.* 100 in Asia Minor should perhaps be attributed to the influence of the much more highly developed contemporary structures in Italy.

[118] Already observed by Herodotus (1.179) and Xenophon (*An.* II.4.12; III.4.7). On Greek examples Martin 1965, 1.63–4: (J 228); Orlandos 1966, 1.67–8: (J 237).

[119] On the Piraeus arsenal see below, p. 380 n. 150.

[120] See Plates vol., pl. 48 (Priene); Krischen 1941, pls. 1–20: (J 223), (Priene and Miletus); McDonald 1943, 217–19 and Pl. 6: (J 232), (Notium); Gruben 1961, 157, 166–7: (J 211) (Sardis). Coulton 1977, 157–8: (J 197), thinks that trusses may not have been fully appreciated even in Hellenistic times.

Hellenistic architectural writers constantly sought to provide a sound theoretical and technical basis for their practical activities, and to apply to inherited architectural forms new and coherent systems of exterior and interior proportions and ornament. Unfortunately most Hellenistic scientific and engineering treatises have perished, along with all their illustrative drawings. These works, however, were eagerly studied by Roman architects such as the Augustan writer Vitruvius, whose work *On Architecture* is easily our most important source for the history of Hellenistic architectural theory.[121] Yet few Hellenistic engineering specialists were also practising architects, or *vice versa*, whereas the Romans regarded mechanical and civil engineering as essential aspects of the architect's profession. Thus between the reigns of Nero and Hadrian Roman engineers produced a genuine architectural revolution, leaving little place for traditional Hellenistic forms except as decorative elements. If Vitruvius' book had not been written before the death of Nero, it might never have been written at all in its present form.

(c) *Hellenistic buildings*

Alongside conventional, though impressive, peripteral and dipteral temples, Hellenistic theorists also produced more original designs, with pseudo-dipteral, 'unfacial' prostyle or *in antis*, and circular plans.[122] While none of these plans was completely new, Hellenistic designers laid greater emphasis on the front, or entrance, of the temple, and blended temple, altar and court (increasingly often colonnaded) into a single coherent scheme.[123] Moreover, Hermogenes' pseudo-dipteral design at Magnesia, and the 'modified pseudo-dipteros' at Sardis, both represent unprecedentedly intricate arrangements of exterior and interior spaces.[124] Classical architecture had concentrated primarily on exterior (and later on interior) forms and their inter-relationships; the finest classical creations are 'really abstract sculpture'.[125] Hellenistic buildings were based on visual and spatial, rather than purely 'formal', relationships: roomy colonnades and porches; systematic ratios for base–diameter, taper, height and spacing of columns; emphatic widening of the central intercolumniation of the façades; contrasting plain and

[121] M. Vitruvius Pollio, *Ten Books on Architecture*, ed. F. Granger (Loeb edition), London and New York, 1934. About four-fifths of the architects, engineers and technical writers mentioned by Vitruvius, and about two-thirds of his Greek buildings, were probably later than *c.* 360.

[122] See Plates vol., pls. 38, 51, 74–5, 87.

[123] E.g. as at Magnesia: Humann 1904, pl. 2: (J 214); essential unity maintained over 150–200 years at Cos and Lindus, cf. Lawrence 1957 pl. 109A: (J 224), and Dyggve 1960, 43, pl. 2A: (J 203).

[124] Despite their size and fame, the great Ionic dipteroi at Ephesus and Didyma, and the Corinthian dipteros of Zeus at Athens, all followed an Archaic pattern, with none of the originality of Magnesia and Sardis.

[125] Lawrence 1957, 293: (J 224).

carved or painted surfaces. Even the façades of uncanonical temples, at sites outside the mainstream of Greek religious architecture, often followed normal principles of Hellenistic design (fig. 9).[126]

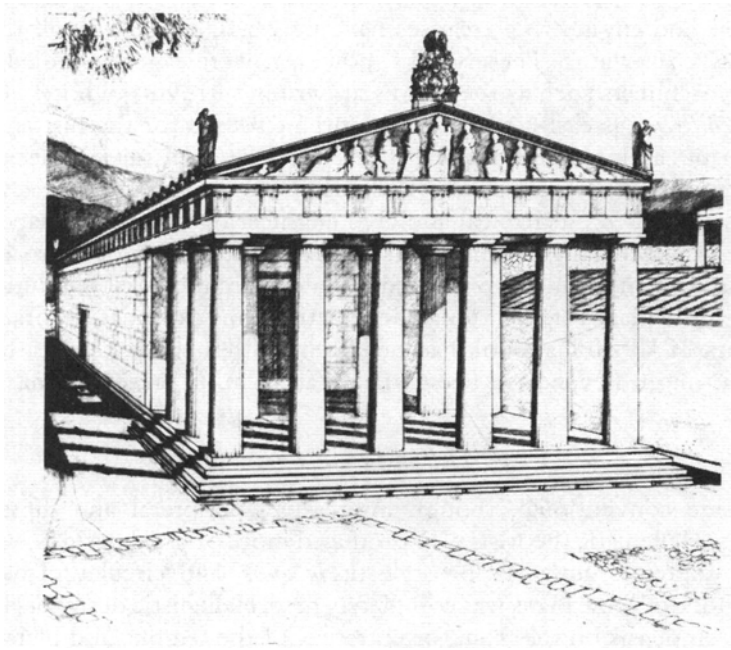

Fig. 9. Restoration of the Hieron, Samothrace. (From Lehmann 1969, III.3, fig. CX: (J225).)

Hellenistic stoas were often two-storeyed, and effectively defined the borders of large open areas, e.g. the Athena precinct at Pergamum, or the Athenian Agora (Stoa of Attalus II).[127] The Sacred Stoa at Priene provided a unifying colonnaded façade for the disparate forms of civic offices, public banquet rooms, assembly-hall and prytaneum; at Athens the Middle Stoa formed an imposing visual link between the Agora proper and the South Square. The East Stoa of the Milesian South Agora housed inward- and outward-facing shops placed back-to-back; at Alinda and Aegae the storerooms and shops, accessible only from the street outside, lay beneath the two-aisled colonnade on the downhill side of the agora.[128] Delian inscriptions even describe the Hypostyle Hall as a stoa;[129] and its relationship to more conventional

[126] E.g. the Hieron on Samothrace: Lehmann 1969, pls. 102, 108, 110: (J 225). Hellenistic theories of visual and spatial relationships surely underlie much of Vitruvius' Books III–IV.

[127] Pergamum: Akurgal 1978, pl. 33a: (J 170); Stoa of Attalus: Plates vol., pl. 86; Thompson and Wycherley (1972) 103–7 and pls. 54–7 (J 251). Cf. Assus, North Stoa: Lawrence 1957, 266 fig. 151: (J 224); Plates vol., pls. 47, 72, 182a.

[128] Bohn 1889, 28 figs. 27–8 (Alinda), 14–27 and figs. 15–16 (Aegae): (J 185).

[129] Vallois and Poulsen 1914, 27–39, 49–54: (J 254).

stoas is certainly clear. Yet the concentric rectangles of interior columns and the small central clerestory make this building at least a collateral ancestor of the Roman basilica;[130] like many basilicas, it was evidently a commercial exchange.[131]

The small upper order (usually Ionic) of two-storeyed stoas presented special problems of design. The spans, the same as those of the large lower order, required sturdy supports; yet short thick columns would have been most unattractive. Half-columns attached to rectangular piers more than doubled the strength of the supports, while keeping the columnar element very slender. Such 'composite' members perhaps originated in the late fourth century.[132] Pergamene architects used columnar elements on both sides of the piers; the parapet was mounted between the piers, the 'columns' continuing down to floor-level on both faces.[133]

In general Hellenistic columnar orders display a remarkable richness and flexibility. After *c.* 440 interior columns in Doric structures were increasingly often non-Doric;[134] in the fourth century these interior orders were frequently half-columns, as at Tegea and in the Philippeum at Olympia. Even the freestanding interior orders at Nemea (Ionic placed above Corinthian, probably copying Tegea[135]) were essentially decorative. After 300 superimposed engaged orders also appeared on façades, e.g. the Gate of Zeus and Hera at Thasos and the Great Tomb at Lefkadhia in Macedonia.[136] The Ptolemaeum on Samothrace even had an outer Ionic and an inner Corinthian façade sharing a common 'Ionic-Corinthian' entablature.[137] In the hypaethral court of the Ionic Didymaeum Corinthian half-columns framed the central doorway to the oracle-room, while piers with 'Corinthianizing' sofa-capitals decorated the remaining wall-surfaces; and three types of column were employed in the Stoa of Attalus at Athens and the Milesian council-house.[138]

This Milesian building, a gift of the Seleucid king Antiochus IV Epiphanes, exemplified the spirit of the new secular architecture: prominent dedicatory inscription, Corinthian propylon, plain Doric for the courtyard, richly ornamental engaged Doric on the exterior of the

[130] Antedating by 20 to 25 years the earliest basilica at Rome, the Porcia, built in 184 (Livy xxxix.44.7; Plut. *Cat. Mai.* 19.3, *Cat. Min.* 5.1). Cf. Plates vol., pl. 130.

[131] On commercial transactions in basilicas see Vitr. v.1.4–5 and 8.

[132] Coulton's (1964, 100–31: (J 195)) date for the L-shaped Stoa at Perachora.

[133] Cf. Travlos 1971, 512–13, 519, figs. 644–5, 656: (J 253); Plates vol., pl. 86.

[134] The new Argive Heraeum, of the late fifth century, was the last important Doric temple to have Doric interior columns.

[135] On the relationship of the Nemea to the Tegea temple see Hill and Williams 1966: (J 212); on Ionic above Corinthian at Tegea Naomi Norman, *AJArch.* 84 (1980) 225.

[136] Martin 1968, fig. 1: (J 229); 1973, 56 fig. 53: (J 230); Plates vol., pl. 67.

[137] J. M. McCredie in U. Jantzen, 1976, 93–5 and fig. 3: (J 215).

[138] Didyma sofa-capitals: Knackfuss 1941, I.2 pls. 112–32, I.3 pls. 32–5: (J 219); Miletus council-house, *idem* 1908: (J 218), Krischen 1941: (J 223). Cf. Plates vol., pls. 86, 210.

council-chamber, freestanding Ionic columns inside (fig. 10). Such buildings served as models for many later bouleuteria and odea.[139] In smaller towns assembly-halls were often plainer, unless they faced a courtyard, the agora, or major streets.[140]

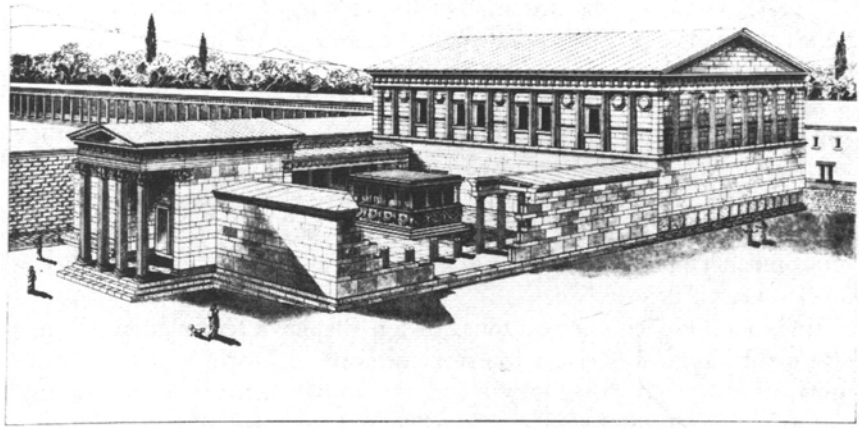

Fig. 10. Restoration of the Bouleuterion, Miletus. (From Knackfuss 1908, 1.2, pl. xiv: (J 218).)

The Corinthian propylon of the Milesian council-house was probably typical of Seleucid decorative architecture; for Corinthian was much more popular in Syria and Egypt than in the Aegean world. The Athenian Olympieum and the contemporary temple of Zeus at Uzuncaburç (Olba) in Cilicia, both begun *c.* 170 by Antiochus IV, are the earliest major Corinthian temples; and the Corinthian capitals from Hermopolis Magna (Upper Egypt) and Aï Khanum (Afghanistan) are among the most impressive Hellenistic examples discovered through excavation.[141]

Corinthian leaf-capitals reached Tarentum soon after 400, and proved instantly popular in Italy.[142] After *c.* 300 Italic developments were strongly influenced by Seleucid and Ptolemaic models, doubtless often imported directly through the Campanian ports. By 150–100 Corinthian was firmly established in Latium, especially for circular

[139] Seleucid connexions of Miletus dedicatory inscription: Knackfuss 1908, 95–100: (J 218). Cf. Milesian building with later buildings, e.g. at Troy and Nysa-ad-Maeandrum, Akurgal 1978, 62, 234–5, and pl. 59b: (J 170). The date of the final remodelling of the 'New Bouleuterion' at Athens (Thompson and Wycherley 1972, 33: (J 251)) is quite uncertain; it may in fact have been based on the Seleucid model.

[140] Quite plain at Priene (Plates vol., pl. 48), more ornamental at Termessus and Alabanda (Akurgal 1978, 243, 327, and pls. 75a, 95a: (J 170)), and at Latmian Heraclea.

[141] Olympieum: Plates vol., pl. 87; Vitr. VII. *Praef.* 15, 17; Uzuncaburç temple: Williams 1974, 405–14: (J 258); Hermopolis Magna: A. J. B. Wace, *Hermopolis Magna* (Alexandria 1959), colour-plate; Aï Khanum: Bernard 1968, fig. 4 and pls. 13, 14: (J 181).

[142] For Corinthian at Tarentum see Ronczewski 1927 and 1934: (J 242–3), and Roux 1961, 376, 381–2: (J 244).

temples.[143] Later Roman 'normal Corinthian' was also indebted to Seleucid work, i.e. the capitals of the Athenian Olympieum sent to Rome by Sulla.[144]

Hellenistic artists and architects frequently borrowed earlier forms and ideas. For example, Pergamene leaf-capitals were evidently derived from archaic palm-capitals, while the Doric half-capitals of the Miletus bouleuterion copied those of the Erechtheum Caryatids (fig. 11). While Ionic ornament already appears in sixth-century Doric, Hellenistic mixing of the orders is much more conspicuous and thoroughgoing. The Italo-Hellenistic style produced the unorthodox 'Italian Temple' at Paestum, and probably also the 'Corinthian-Doric' Inner Propylaea at Eleusis;[145] Seleucid and Anatolian designers successfully combined Attic and 'Asiatic' Ionic bases and entablatures;[146] and 'mixed orders' appear in stoas and elsewhere (fig. 11).[147] Indeed Hellenistic architects

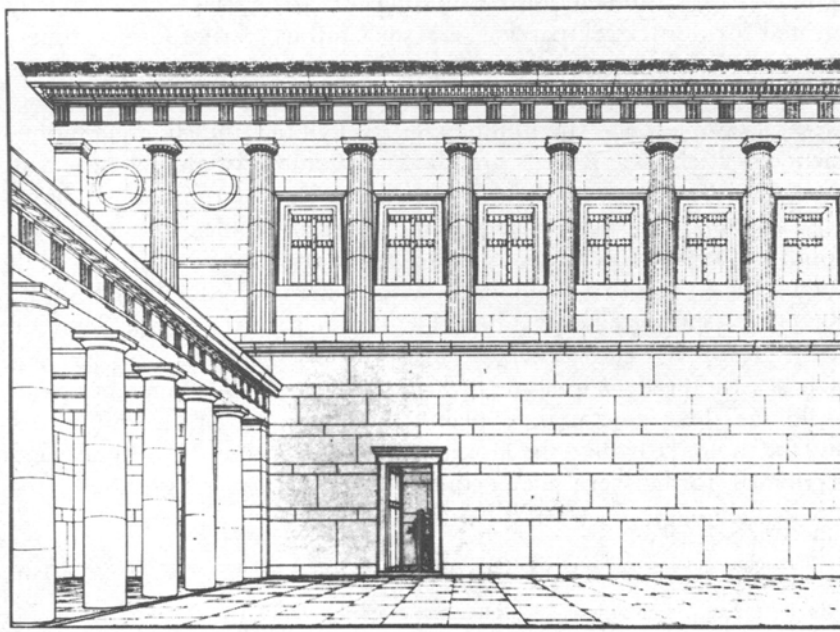

Fig. 11. Restoration of the interior of the Bouleuterion, Miletus. (From Krischen 1941, pl. 4: (J 223).)

[143] E.g. Temple B in the Largo Argentina at Rome (mid second century) and the round temple at Tivoli (early first century); cf. Boethius 1970, pls. 76 and 83: (J 184). [144] Pliny, *HN* XXXVI.45.

[145] Paestum: Krauss and Herbig 1939: (J 222); Eleusis: Hörmann 1932, pl. 35: (J 213).

[146] Attic-Ionic bases on plinths: Corinthian half-columns at Didyma, Corinthian columns of the Belevi mausoleum; combination of frieze-band and dentils: Belevi and the new *naiskos* at Didyma. Seleucid involvement is possible in all these examples. Plates vol., pl. 243.

[147] Pergamum, Athena precinct: Lawrence 1957, 209 fig. 115: (J 224); Priene, North Stoa of agora: Martin 1973, 38 fig. 34: (J 230).

increasingly treated the orders as a single repertoire of architectural ornament, permitting many different combinations. By liberating essentially ornamental details from rigid rules based on the assumption that the forms in question were still structural, they avoided the frequent awkwardness of archaic and classical work.[148]

Sometimes even utilitarian storage-buildings achieved the visual effectiveness recommended by Aristotle for city-walls.[149] The Piraeus arsenal, planned by Aristotle's contemporary Philo of Eleusis, who also wrote a treatise on temple-design, was famous for its harmony and elegance (fig. 8).[150] Storehouses also illustrate the technical proficiency of Hellenistic architecture. Thus Philo of Byzantium describes granaries with floors suspended on transverse arches or on barrel-vaults;[151] and the Pergamene arsenals were plain wooden sheds erected over intricate stone basements that ensured good ventilation.[152]

Large-scale commemorative buildings of Greek style were originally created for non-Greek patrons, e.g. at Xanthus (early fourth century) and Limyra (perhaps *c.* 360) in Lycia,[153] and the gigantic tomb of the Carian dynast Mausolus at Halicarnassus, begun *c.* 360–355.[154] Purely Greek examples, e.g. the Philippeum at Olympia, the choragic monument of Lysicrates at Athens, and the Lion Tomb at Cnidus, all post-date 350. Commemorative monuments of the 'temple-tomb-on-podium' type are important descendants of the classical temple, often using the columnar orders in new contexts. Moreover, the superstructures of built tombs, like the earth-mounds of Macedonian tumulus-burials, were sometimes supported on vaulted chambers, e.g. in the Charmyleum on Cos.[155]

If the tholoi at Delphi and Epidaurus were also 'commemorative' buildings, their fame might explain the circular plan of the Philippeum and the tholos crowning the Monument of Lysicrates.[156] Curvilinear and rectilinear forms were again combined in the great lighthouse, the

[148] Cf. Coulton 1977, 139: (J 197).

[149] Arist. *Pol.* VII.1331a.

[150] Building described at length in *IG* II².1668; treatise by the architect, Vitr. VII. *Praef.* 12, cf. Cic. *De Or.* I.14.62.

[151] Philo 87.9.31 and Diels and Schramm 1919 (1920), 42 fig. 22: (J 27).

[152] See Szalay and Boehringer 1937: (J 250).

[153] Nereid Monument: Demargne and Coupel (1969): (J 201); Limyra: Borchhardt 1970 and 1976: (J 186–7).

[154] On the Mausoleum see Jeppesen 1976: (J 217); Hornblower 1982, 223–74: (E 73). The monument was obviously commissioned by Mausolus some time before his own death, though work was still continuing after Artemisia's death in 351 (Pliny, *HN.* XXXVI.30–1).

[155] For Lefkadhia, Great Tomb: Martin 1973, 353 figs. 396–7: (J 230); Charmyleum: P. Schazmann, 'Das Charmyleion', *JDAI* 49 (1934) 110–27, S. M. Sherwin-White 1978, 365–6 with notes: (D 146).

[156] Tholoi: Berve and Gruben 1978, 96: (J 182) (Delphi), but see also Chr. Le Roy, *Études Delphiques* (Paris 1977) 247–71, esp. 250–1; Berve and Gruben 1978, and Roux 1961, 131–200: (J 244) (Epidaurus).

Pharos, at Alexandria,[157] and in many later Hellenistic and Roman memorials.

As architectural types, gymnasia and stadia were also Hellenistic creations. Again the columnar orders played important decorative roles, e.g. in the porticos of gymnasia or palaestrae, the entrance to the 'ephebeum' of the Lower Gymnasia at Priene, and the starting-gates of stadia.[158] Furthermore, Hellenistic engineers evidently designed, for palaestrae and related structures, the first hot baths with the sub-floor system of heating from which Roman hypocausts later developed.[159]

Until *c.* 350 Athenian dramas were probably performed on a low wooden platform slightly above orchestra-level, in front of a wooden stagehouse (*skene*).[160] The high Hellenistic stage seems to have developed *c.* 350–325 from Athenian experiments in staging later Middle Comedy. These experimental wooden *skenai* were two-storeyed; the stage was a flat-roofed, single-storeyed *proskenion* (= part in front of the *skene*), with the *episkenion* (upper storey of the *skene*) serving as backdrop.[161] The *proskenion* was provided with practicable doors, and was used as backdrop for performances at or near orchestra-level, in the older manner. Current views notwithstanding, the earliest *skene–proskenion* in stone was most probably built at Athens no later than *c.* 300; Athenian New Comedies were all produced on this stone *proskenion*-stage or its wooden predecessors. By *c.* 300–280 stone *proskenia* were being built elsewhere, doubtless under Athenian influence.[162]

Stone *proskenia* with colonnaded façades, and practicable doors of adequate width, required sturdy supports. Here again, Hellenistic designers substituted slender half-columns, attached to piers, for freestanding columns. These composite members were structurally sound as well as visually attractive, and door-frames and painted scene-

[157] Pharos: Dinsmoor 1950, pl. 68: (J 202).

[158] Courts of the gymnasia at Delphi and Epidaurus: Jannoray 1953: (J 216) and Dinsmoor 1950, 320–1 and fig. 116: (J 202); Priene gymnasium and stadium: M. Schede, *Die Ruinen von Priene* (Berlin 1934) fig. 99. Cf. Plates vol., pls. 54, 72, 182a.

[159] The discovery of simple hypocausts of middle and late Hellenistic date, in the Asclepieum baths of Arcadian Gortys (Ginouvès 1959: (J 209)), suggests that the Romans used Greek terms such as *thermae* and *hypocaustum* because the basic development work had been Greek. The 'Greek hypocaust bath' at Olympia should probably be regarded as an early example of Italic influence (Plates vol., pl. 183).

[160] In one form or another this view is espoused by almost all recent students of Greek drama; see Arnott 1971, 23–5: (J 173); Webster 1970, 7: (J 257); Baldry 1971, 44–5: (J 175).

[161] See Plates vol., pls. 193a–b.

[162] E.g. at Thasos (Salviat *et al.* 1968), 50–4 and figs. 18–19: (J 245)), and despite the objections of some scholars, also at Epidaurus, where von Gerkan's arguments for an early Hellenistic *proskenion* have yet to be shaken (Gerkan 1961, 45–83, esp, 77–80: (J 208)). The stone *proskenion* of the deme-theatre at Trachones, near Athens, whatever its exact date, presumably copied the first stone *proskenion* in the theatre of Dionysus at Athens; cf. Winter, 'The stage of New Comedy', *Phoenix* 37 (1983) 38–47. Cf. Plates vol., pls. 195a–b.

panels (*pinakes*) could easily be mounted between them.[163] The *episkenion* façade had few fixed elements in stone, usually consisting of three or more large openings (*thyromata*) between stone piers. These openings could accommodate painted scenery; alternatively, a set just inside the *thyroma* might represent an interior.

Greeks west of the Adriatic early developed a tradition of acting on a wooden stage of medium height, against a backdrop of wooden architecture. By *c.* 300 some stagehouses had two tiers of columns crowned by a pediment.[164] The Western stagehouse was combined with a high Aegean *proskenion* in the late Italo-Hellenistic theatre at Segesta in Sicily, but was taken over unchanged for the wooden theatres of Republican Rome.[165] These in turn inspired the permanent masonry *scenae frons*, first encountered at Rome in Pompey's theatre. Despite some experiments, both in theatres and in stadia, with seating-areas suspended on stone vaults,[166] there are no real Hellenistic antecedents for Pompey's auditorium, entirely supported on vaulted underpinnings.

Few examples of Hellenistic palace and villa architecture are known from the Eastern Mediterranean. Nevertheless, the impressive Macedonian complex at Palatitsa, above Vergina, is the first genuine palace extant in mainland Greece since the Mycenaean age (Plates vol., pl. 69); both this palace and the Hellenistic villa, or palace, overlooking the sea at Samos offer typically Hellenistic vistas of land- and seascape.[167] The stepped, multi-level design of the House of the Hermes on Delos is virtually unique before the Roman period; and the Delian 'Granite Building' and block of the House of the Comedians were apparently both responses to the need for extensive rental accommodation within a relatively small area. These two units are thus Aegean relatives of the Roman Republican *insula*.[168] Moreover, while Pergamum and Antioch evidently produced little or no real palace architecture, the Alexandrian literary evidence indicates that Italic and Roman palaces and villas borrowed heavily from Ptolemaic Egypt. The lavish symposium-tent of Ptolemy II, described by Callixeinus of Rhodes, was clearly a temporary version of the Ptolemaic *basilikai aulai* (royal halls) that were the chief ancestors of Roman civil and residential basilicas;[169] and Callixeinus'

[163] See the cuttings for mounting *pinakes* in the *proskenion*-piers at Priene, Wiegand and Schrader 1904, fig. 246: (B 212); also Coulton 1977, 137: (J 197).

[164] As in the Naples plaque: Bieber 1961, 130 fig. 480: (J 183). See Plates vol., pl. 208.

[165] Bieber 1961, 170 figs. 600–1: (J 183); Boethius 1970, 166–9: (J 184).

[166] Alinda: Boyd 1978, 96 and 111.4: (J 188); Letoon theatre near Xanthus: Martin 1973, 43 fig. 39: (J 230); stadia: Boyd 1978, 91 and n. 32, 100: (J 188).

[167] Palatitsa: Andronikos *et al.* 1961: (J 172); Samos: Tölle-Kastenbein 1974: (J 252).

[168] Comedians, Bruneau *et al.* 1970: (J 190); Hermes: Bruneau and Ducat 1966, 134–7: (J 189); Plates vol., pl. 137; 'Granite Building': Gallet de Santerre 1959, 73–107 and esp. 104–5: (B 196).

[169] Ath. *Deipn.* II.196b – 197c on the symposium-tent; cf. with Vitr. VI.3.9 (Egyptian *oikoi*) and VI.5.2 ('residential' basilicas).

account of the basilican dining-halls and other appointments of the river-barge of Ptolemy IV vividly reflects the splendour of polychrome masonry, luxurious wood-panelling, and gilded ivory decoration employed in Ptolemaic palace-architecture. Ptolemaic palaces in fact remained unrivalled until the time of Nero and the Flavians; yet both in Alexandria and at Vergina and Samos, Greek, or Graeco-Egyptian, columnar orders formed the basis of most of the designs.[170]

In sum, from the later fourth century onward Hellenistic architects made great strides in many areas. They created a third complete order out of late classical experiments with the Corinthian capital; reshaped all three orders into a rich and flexible idiom adaptable to many different contexts; devised new types of temples and of monumental tombs and other commemorative structures; gave clear architectural form to Greek stagehouses and gymnasia; worked out effective designs for warehouses and covered halls, including prototypes of the Roman basilica; exploited the potential of the stoa for monumental definition of the borders of agora and sanctuary complexes; developed the first hypocaust heating-systems; and produced both the first examples of Greek palace-architecture since the Bronze Age, and some of the prototypes of later Roman villas and *insulae*. Probably no other period, either of Greek or of Roman architecture, can advance as impressive a claim to originality as the centuries from *c.* 350 to 100.[171]

[170] River-barge: Ath. *Deipn.* II.205a–206c; gardens in the Alexandria palaces: Strabo XVII.794.
[171] Adriani 1963, 290–311, and esp. 290, 'General Characteristics': (J 169).

HELLENISTIC DYNASTIES

1. THE PTOLEMIES

Ptolemy I Soter	305–283
Ptolemy II Philadelphus	283–246
Ptolemy III Euergetes I	246–221
Ptolemy IV Philopator	221–204
Ptolemy V Epiphanes	204–180
Ptolemy VI Philometor	180–145
with Ptolemy VIII Euergetes II and Cleopatra II	170–164
with Cleopatra II	163–145
Ptolemy VIII Euergetes II (restored)	145–116
Cleopatra III and Ptolemy IX Soter II (Lathyrus)	116–107
Cleopatra III and Ptolemy X Alexander I	107–101
Ptolemy X Alexander I and Cleopatra Berenice	101–88
Ptolemy IX Soter II (restored)	88–81
Cleopatra Berenice and Ptolemy XI Alexander II	80
Ptolemy XII Neos Dionysus (Auletes)	80–58
Berenice IV (at first with Cleopatra Tryphaena)	58–56
Berenice IV and Archelaus	56–55
Ptolemy XII Neos Dionysus (restored)	55–51
Cleopatra VII Philopator	51–30

2. THE SELEUCIDS

Seleucus I Nicator	305–281
Antiochus I Soter	281–261
Antiochus II Theos	261–246
Seleucus II Callinicus	246–226/5
Seleucus III Soter	226/5–223
Antiochus III Megas	223–187
Seleucus IV Philopator	187–175
Antiochus IV Epiphanes	175–164
Antiochus V Eupator	164–162
Demetrius I Soter	162–150
Alexander Balas	150–145
Demetrius II Nicator	145–140
Antiochus VI Epiphanes	145–142/1 or 139/8
Antiochus VII (Sidetes)	138–129
Demetrius II Nicator (restored)	129–126/5
Cleopatra Thea	126/5–123

Antiochus VIII Grypus	126/5–96
Seleucus V	126
Antiochus IX Philopator (Cyzicenus)	114/13–95
Seleucus VI	95
Antiochus X Eusebes Philopator	95
Demetrius III Philopator Soter	95–88 (at Damascus)
twins: Antiochus XI Epiphanes Philadelphus	95 (in Cilicia)
twins: Philip I	95–84/3 (in Cilicia)
Antiochus XII Dionysus	87 (at Damascus)
Philip II	84/3

3. RULERS OF MACEDONIA BEFORE ANTIGONUS GONATAS

Philip III Arrhidaeus	323–317
Olympias	317–316
Cassander (king from 305)	316–297
Philip IV	297
Antipater	297–294
Alexander V	297–294
Demetrius I Poliorcetes	294–288
Lysimachus	288–281
Ptolemy Ceraunus	281–279

4. THE ANTIGONIDS

Antigonus I (Monophthalmus)	306–301
Demetrius I (Poliorcetes)	307–283
Antigonus II (Gonatas)	283–239
Demetrius II	239–229
Antigonus III (Doson)	229–221
Philip V	221–179
Perseus	179–168

5. THE ATTALIDS

(Philetaerus	283–263)
(Eumenes I	263–241)
Attalus I Soter	241–197
Eumenes II Soter	197–159/8
Attalus II	159/8–139/8
Attalus III	139/8–133
(Eumenes III (Aristonicus)	133–129)

CHRONOLOGICAL TABLE (323–217 B.C.)

	Sicily, South Italy, Carthage	Greece and Macedonia	Aegean, Egypt, Cyrene, Asia	Literature, Philosophy, Science, Art
			June 323 Death of Alexander at Babylon. Organization of succession. Division of the satrapies.	
		323 Lamian War breaks out. Athens and Aetolia allied. Antipater shut up in Lamia.	323/2 Revolt of the Greeks in Bactria.	
	c. 322 Return of Agathocles from S. Italy to Syracuse.	322 Athenian naval defeats. Aug. Battle of Crannon. Oligarchic government set up at Athens.	322 Spring. Perdiccas conquers Cappadocia: Eumenes as satrap.	322 Hypereides' Funeral Oration. Deaths of Aristotle, Demosthenes and Hypereides. Theophrastus succeeds Aristotle as head of the Peripatetic School.
		321 Polyperchon organizes Greece.	322/1 Ptolemy conquers Cyrenaica. 321 Campaign and death of Perdiccas in Egypt. Defeat of Craterus in Asia Minor. Conference at Triparadisus. Antipater declared regent.	321 First production of Menander. *c.* 371–*c.* 287 Theophrastus. 341–281 Epicurus.
320	*c.* 320 Agathocles forced to leave Syracuse again.			*c.* 320 Praxagoras *flor.* Hecataeus of Abdera writing in Egypt before 315.
		319 Polyperchon regent. War between Polyperchon and Cassander. Execution of Demades.	319 Death of Antipater. Ptolemy's first invasion of Syria-Phoenicia.	
	319/18 Agathocles appointed general and guardian of the peace at Syracuse.	318 Execution of Phocion. 317 Polyperchon declares the Greeks free. Athens, controlled by Demetrius of Phalerum, makes a treaty with Cassander. Polyperchon restricted to the Peloponnese. Cassander regent of Macedonia. Autumn. Philip III assassinated.	318 Coalition of Cassander and Antigonus against Polyperchon. Eumenes makes gains in Asia at the expense of Ptolemy and Antigonus.	

	Sicily, South Italy, Carthage	Greece and Macedonia	Aegean, Egypt, Cyrene, Asia	Literature, Philosophy, Science, Art
		316 Cassander takes Pydna and has Olympias executed. Foundation of Cassandreia and Thessalonica. Thebes rebuilt by Cassander.	316 Eumenes defeated, captured by Antigonus and executed.	
	316/15 Agathocles elected *strategos autokrator* at Syracuse. 316/15–306/5 Struggle of the exiles in Sicily against Agathocles.			
315			315 Seleucus, expelled from Babylon by Antigonus, takes refuge with Ptolemy. Lysimachus, Ptolemy and Cassander present an ultimatum to Antigonus. Antigonus' proclamation at Tyre: war on Cassander, freedom for the Greeks. Ptolemy proclaims the freedom of the Greek cities.	*c.* 315 Death of Aeschines.
			315/14 Foundation of *koinon* of the Nesiotes by Antigonus. 313 Capital of Egypt moved from Memphis to Alexandria. 312 Victory of Ptolemy and Seleucus over Demetrius Poliorcetes at Gaza. Return of Seleucus to Mesopotamia-Babylonia. Beginning of the 'Seleucid Era'.	314 Death of Xenocrates, head of the Academy; succeeded by Polemon.

	312/11 Outbreak of war against Carthage in Sicily. 311 June. Carthaginians defeat Agathocles on the southern Himera, and blockade Syracuse by sea and land.		311 Peace between Antigonus, Ptolemy, Lysimachus and Cassander. 311–301 Seleuceia-on-the-Tigris capital of the Seleucid kingdom.	312/11 Zeno comes to Athens.
310	Aug. 310–Oct./Nov. 307 Agathocles' African expedition; parts of Punic Libya annexed. *Antander represents* Agathocles in Syracuse. 309 Syracusans defeat Carthaginians under Hamilcar. Land blockade of Syracuse abandoned. 309/7 Liberation movement in Acragas. 309 Spring (?). Alliance between Agathocles and Ophellas of Cyrene. 308 Oct./Nov. Murder of Ophellas. 307 Oct./Nov. Agathocles' catastrophe in Africa; he returns to Syracuse leaving his army in Africa. Nov. Treaty between Carthage and the Syracusan army.	310 Cassander assassinates Alexander IV. 309 (or 308) Reconciliation between Cassander and Polyperchon. 308 Temporary reconciliation between Ptolemy and Antigonus. Ptolemy in Greece. 307 Demetrius Poliorcetes takes Athens from Cassander. Demetrius of Phalerum expelled. Cassander's offensive against Ptolemy in Greece.	310 Menelaus, Ptolemy's brother, made *strategos* of Cyprus, which Ptolemy had annexed. Breach between Ptolemy and Antigonus. 309/8 (?) Antigonus expelled from Iran by Seleucus. 308 (or 305)–303 War between Seleucus and Chandragupta.	

	Sicily, South Italy, Carthage	Greece and Macedonia	Aegean, Egypt, Cyrene, Asia	Literature, Philosophy, Science, Art
			306 Antigonus and Demetrius take Cyprus from Ptolemy. The Antigonids assume the royal title.	307/6 Theophrastus exiled from Athens. 306 Epicurus opens a school in Athens.
	306/5 Peace between Agathocles and the Carthaginians: the Halycus to be the boundary of the Punic dominion in Sicily.			
305	305 Agathocles' victory over the exiles under Deinocrates.		305/4 Demetrius fails to take Rhodes. Ptolemy, Lysimachus, Seleucus and Cassander take the title of King.	
	304 Agathocles takes the title of King.			
	303/2–293 Agathocles in S. Italy; struggle with the Bruttii.	303 Demetrius expels Cassander from the Isthmus.	303 Agreement between Seleucus and Chandragupta.	
	303/2 Cleonymus at Tarentum. Tarentine appeal to Agathocles.	302 New 'League of Corinth' founded by Antigonus and Demetrius. Pyrrhus expelled from Epirus.		
			301 Coalition against Antigonus: his defeat and death at Ipsus. Partition of his kingdom: Ptolemy occupies Coele-Syria.	
300	*c.* 300 Agathocles takes Corcyra. Marriage of Agathocles to Theoxene, daughter or stepdaughter of Ptolemy I.		*c.* 300 Alliances between Ptolemy and Lysimachus and between Demetrius and Seleucus. Magas put in charge of Cyrene.	*c.* 300 Euclid *flor.*

			300–297 Demetrius as ally of Ephesus makes war on Priene. 300/299 Foundation of Seleuceia-in-Pieria and Antioch.	
		298 (or 297) Death of Cassander and of his son, Philip IV. Pyrrhus back in Epirus.	297/6 Beginning of the Bithynian era. Pontic era subsequently back-dated to this year.	*c.* 297 Demetrius of Phalerum in Alexandria. Foundation of the Museum and Library at Alexandria.
		296 Demetrius Poliorcetes in Greece.		
295	*c.* 295 Marriage of Agathocles' daughter Lanassa to Pyrrhus.	295 Lachares seizes power at Athens.	295/4 Ptolemy recovers Cyprus.	
		294 Demetrius recovers Athens. 294–287 Oligarchic government in Athens. Demetrius king in Macedonia.	294 Antiochus I co-regent with Seleucus; in Iran.	
		293 Demetrias founded. Lysimachus briefly a prisoner of the Getae.		293/2 Death of Menander.
		291/2 Boeotia in alliance with Aetolia rises against Demetrius. Demetrius fighting against Aetolia and Pyrrhus.		
	c. 291 Lanassa marries Demetrius Poliorcetes.	291/90 Pyrrhus receives Corcyra as dowry from Agathocles.	291 and in the following years. Ptolemy establishes a protectorate over the Aegean islands.	

	Sicily, South Italy, Carthage	Greece and Macedonia	Aegean, Egypt, Cyrene, Asia	Literature, Philosophy, Science, Art
290	*c.* 290 Alliance between Agathocles and Demetrius: plan for a new Punic war.			
	289/8 Death of Agathocles. Syracuse free.			
		288/7 Invasion and partition of Macedonia by Lysimachus and Pyrrhus.	288/7 Ptolemy takes Tyre and Sidon from Demetrius.	
		287 Athens under Olympichus revolts from Demetrius, who retains Piraeus.	286 Demetrius captured by Seleucus in Asia.	*c.* 287 Death of Theophrastus: Strato of Lampsacus succeeds him as head of the Lyceum. *c.* 287–212 Archimedes.
285		285 Lysimachus seizes Pyrrhus' share of Macedonia.	285 March/April. Ptolemy II co-regent with Ptolemy I.	
		284/3 (or 283/2) Dynastic crisis in court of Lysimachus.	283 Death of Demetrius Poliorcetes. Death of Ptolemy I. Ptolemy II reigns as sole king.	283 onwards. Callimachus, Apollonius, Theocritus, Herondas and the Tragic Pleiad active at Alexandria under Ptolemy II.
			282/1 Seleucus invades Asia Minor: death of Lysimachus at Corupedium (*c.* Feb. 281).	
		281 Sept. Seleucus assassinated by Ptolemy Ceraunus, who becomes king of Macedonia after defeating Antigonus Gonatas.	281 Mithridates I king of Pontus. Antiochus I sole king in Seleucid kingdom.	
280	280–275 Pyrrhus' campaigns in Italy and Sicily.	280 Gauls invade Thrace and Macedonia: defeat and death of Ceraunus. Achaean League refounded.		*c.* 280 Zenodotus and Lycophron active. *c.* 280–245 Aristarchus of Samos *flor.* *c.* 280 Euhemerus *flor.* *c.* 280–*c.* 206 Chrysippus.

		280/79 Decree honouring Demosthenes proposed by Democharis. The Aetolians and other Greeks repel the Gauls from central Greece.	280/79 Syrian war of succession between Antiochus I and Ptolemy II.	
		279 The Gauls establish the kingdom of Tylis in Thrace.	279 *Ptolemaieia* celebrated at Alexandria.	
		278 Reconciliation of Antiochus I and Antigonus Gonatas.	Nicomedes I succeeds Zipoetes in Bithynia. 278/7 Gaulish invasion of Asia Minor under Lutarius and Leonnorius.	
		277 Antigonus II defeats the Gauls at Lysimacheia and becomes king of Macedonia. Spring. Delphi: two Aetolian *hieromnemones* at the Amphictyony; Thessalians preside. Aetolians gain control of the Amphictyony.		*c.* 276–*c.* 196 Eratosthenes. 276/5 Aratus of Soli at court of Antigonus Gonatas.
		276/5 (or 275/4) Aegium joins the Achaean League. 276 Aetolians seize Dolopia. Thessalians disappear from Amphictyonic lists with Gonatas master of Thessaly.		
275			275 (?) Magas of Cyrene attacks Egypt. *c.* 275 Antiochus I grants land to Aristodicides. 275/4 Philetaerus begins to strike coins at Pergamum.	*c.* 275 Theocritus' *Idyll* XVII.
		274 Pyrrhus conquers Macedonia.	Before 274 Ptolemy II marries Arsinoe. 274–271 First Syrian War between Ptolemy II and Antiochus I.	

	Sicily, South Italy, Carthage	Greece and Macedonia	Aegean, Egypt, Cyrene, Asia	Literature, Philosophy, Science, Art
		273 Pyrrhus' son Ptolemy defeats Gonatas. 272 Spring. Pyrrhus invades Peloponnese. Delphi: five Aetolian *hieromnemones*. Aeniania absorbed. Summer. Pyrrhus at Sparta. Autumn. Death of Pyrrhus at Argos. Aristippus tyrant at Argos. (?) Aristodamus tyrant at Megalopolis. (?) Athenian–Aetolian treaty. Aristotimus, tyrant of Elis, murdered.	272/1 Arsinoe and Ptolemy II receive divine honours.	
		271 (?) Gonatas recovers Chalcis. 271/70 Athens passes a decree honouring Democharis.	271 End of First Syrian War. 271/70 (?) Procession of Ptolemy II in Alexandria.	
270			270 Death of Arsinoe (July). *c.* 270 Antiochus I defeats Gauls in the 'elephant-battle'.	270 Death of Epicurus. *c.* 270 Ctesibius *flor.*
		270/69 Athenian decree for Callias of Sphettus. 268/7 Peithidemus archon at Athens. Decree of Chremonides (autumn 268). 267–261 Chremonidean War. 267 Rhamnus held by Athens and allies. Athenian traitors helping pirates allied to Gonatas.		*c.* 269 Death of Strato. *c.* 268–265 Death of Polemo: succeeded briefly by Crates and then by Arcesilaus as head of the Academy.

		Gonatas and Patroclus in Attica. First Spartan expedition: reaches Isthmus. 266 Second Spartan expedition checked at Isthmus. Gonatas suppresses Galatian mercenaries at Megara. Siege of Athens. 266/5 Nicias 'Otryneus' archon at Athens.	267 Inscription from Denizli honours Achaeus, a Seleucid functionary.	
265		265 Third Spartan expedition: Areus defeated and killed near Corinth. 265–262 Athens holds out.		
	264 241 First Punic War between Rome and Carthage.	264 Cleinias murdered at Sicyon: Aratus in Argos. 264/3 Diognetus archon at Athens.	*c.* 264 Nicomedia founded. 263 Eumenes I succeeds Philetaerus at Pergamum (without royal title).	
		262/1 Antipater archon at Athens.	*c.* 262/1 Ephesus under the Ptolemies.	262 Reclamation work in the Fayyûm.
		261 Alexander of Epirus invades Macedonia and is expelled from Epirus. Renewed siege of Athens which falls to Gonatas. Amphictyons accept the Alexandrian *Ptolemaieia*. Peace between Gonatas and Athens. (?) Aetolian–Acarnanian treaty. Alexander restored in Epirus.	261 Death of Antiochus I: Antiochus II succeeds him. *c.* 261 Apollonius becomes *dioiketes* of Ptolemy II. Zeno of Caunus arrives in Egypt. (?) Battle of Cos: 'peace in the Aegean'. Gonatas attacks Miletus.	261 Death of Zeno: succeeded by Cleanthes of Assus as head of the Stoa.
260			260–253 Second Syrian War: Ptolemy II against Antiochus II. *c.* 260 Bilingual edict of Aśoka (Greek and Aramaic) at Kandahar.	*c.* 260 Erasistratus *flor.* *c.* 260/250 Death of Herophilus (330/320–260/250).

	Sicily, South Italy, Carthage	Greece and Macedonia	Aegean, Egypt, Cyrene, Asia	Literature, Philosophy, Science, Art
				c. 260 Apollonius Rhodius head of the Library at Alexandria.
			259 Revenue Laws promulgated in Egypt.	
			258 Ephesus once more Seleucid.	
		c. 257 Demetrius becomes co-regent with Gonatas.		
		256/5 'Liberty restored' at Athens.	256–250 Beginning of the Parthian breakaway.	
255		255 One general substituted for two in Achaea.	*c.* 255 Beginning of the Cappadocian royal era.	*c.* 255 Death of Timaeus (*c.* 350–*c.* 255).
		c. 255 Argos free of Macedonia.	*c.* 255/4 Ziaelas gains control of Bithynia.	
			253 (?) End of Second Syrian War.	
			253 Gonatas founds the *Antigoneia* and *Stratoniceia* at Delos.	
			c. 253–251 Ptolemy II re-establishes good relations with Magas of Cyrene.	
			252 Antiochus II marries Berenice II.	
		c. 251 Megalopolis freed: death of Aristodamus.		
		251 Jan. Nicocles tyrant at Sicyon: Aratus' attack fails.		
		May. Aratus frees Sicyon.		
		Sicyon joins the Achaean League.		
		251/50 Aratus visits Egypt.		
		Ptolemaic subsidy for Achaea.		
250		*c.* 250 Death of Craterus governor of Corinth.	250 Death of Magas of Cyrene.	
		250–248 Aristomachus I tyrant of Argos.	Demetrius the Fair called in: murdered by Berenice.	
		Aratus attacks Alexander, governor of Corinth.	Cyrenaica falls to Ptolemy.	
			Death of Nicomedes I of Bithynia.	

		Alexander revolts from Gonatas and makes a treaty with Achaea. Gonatas attacks Corinth from Athens and Argos. Peace between Gonatas and Alexander.	*c.* 250–237 Secession of Bactria and Parthia from the Seleucids.	
		246 Aetolians make the *Soteria* quadrennial.	247 Beginning of Parthian era. 246 Deaths of Ptolemy II and Antiochus II: succeeded by Ptolemy III and Seleucus II. Revolt in Egypt. 246–241 Third Syrian (Laodicean) War: Ptolemy III against Seleucus II. 246 Ptolemy III reaches Ephesus and goes thence to the Euphrates and Mesopotamia: Antiochus Hierax in charge in Asia Minor. (?) Battle of Andros: Gonatas defeats Sophron.	*c.* 246 Erastosthenes head of the Library at Alexandria. 246 Callimachus' *Coma Berenices.*
245		245 May. Aratus' first generalship in Achaea. ? Death of Alexander of Corinth. Autumn. Aetolians defeat Boeotians at Chaeronea. Gonatas recovers Corinth. Beginning of his 'system of tyrants'. Suppression of the Euboean League. 245/4 First performance of new Delphic *Soteria*. 244 (?) *Isopoliteia* between Messenia and Phigalea. Lydiades tyrant at Megalopolis. (or later) Elis acquires Triphylia. (or 243) Agis IV ascends the throne at Sparta.	245 Gonatas institutes *Paneia* and *Soteria* at Delos. Seleucus II recognized in Babylon. 245–241 Ptolemaic forces active on the southern and western shores of Asia Minor.	

	Sicily, South Italy, Carthage	Greece and Macedonia	Aegean, Egypt, Cyrene, Asia	Literature, Philosophy, Science, Art
		243 May Aratus general for second time. Summer Aratus seizes Corinth. Megara, Troezen and Epidaurus join the Achaean League. (?) Gonatas and the Aetolians agree to partition Achaea. (?) Alexander of Epirus and the Aetolians agree to partition Acarnania Autumn. Lysander ephor at Sparta. 242 Spring. Aratus invades Attica and Salamis. Leonidas in exile at Tegea Spartan reforms (debts cancelled). Achaeo-Spartan alliance. Autumn. Agesilaus ephor at Sparta.	242/1 Antiochus Hierax, co-ruler with Seleucus II, controls lands west of the Taurus Mountains.	
	241 End of the First Punic War.	241 May. Aratus general for third time. Autumn. Aratus and Agis at the Isthmus Agis is sent back Aetolian defeat at Pellene. Fall of Agis and Agesilaus at Sparta. 241/40 (?) Aratus seizes Cynaetha. Peace between Aetolia, Gonatas and Achaea. 240 Aratus' regular attacks on Athens begin. Aratus' attacks on	241 End of Third Syrian War Death of Eumenes I. Accession of Attalus I. 240/39–*c.* 237 War of the Brothers: Seleucus II against Antiochus Hierax.	241/40 Death of Arcesilaus: Lacydes succeeds him as head of the Academy

240	240–237 Carthaginian Mercenary War.	Aristomachus and later Aristippus of Argos. *c.* 240 Death of Alexander II of Epirus: Olympias regent. 240/39 Death of Antigonus Gonatas: Demetrius II succeeds.	240 (or 239) Seleucus defeated by Hierax: retires to Cilicia. *c.* 240 Foundation plaques of the great Serapeum of Alexandria.	
		239 Aetolian attacks on Epirote Acarnania. Achaean attacks on Athens and Argos continue. Alliance between Macedonia and Epirus: Demetrius marries Phthia. (?) Aetolo-Achaean alliance between Aratus and Pantaleon. May. Aratus' fourth generalship. 239/8 (?) Outbreak of Demetrian War (in the archonship of Lysias at Athens).	239 Attalus defeats Antiochus Hierax and takes the royal title. Canopus decree. (?) Diodotus of Bactria takes royal title.	
		237 May. Aratus' fifth generalship. (?) Demetrius invades Boeotia. 237/6 (or before 228/7) Opus leaves Aetolia and joins Boeotia.	*c.* 237 End of the War of the Brothers. 237/6 Demetrius II's alliance with Gortyn.	
235		236 Dioetas Achaean general: Achaeans take Heraea. 235 May. Aratus' sixth generalship. Aratus' attacks on Argos. Aratus' seizure of Cleonae. Death of Aristippus: Aristomachus tyrant of Argos. Lydiades abandons his tyranny. Megalopolis joins the Achaean League. (?) Tegea, Mantinea, Orchomenus and Caphyae join the Achaean League. Cleomenes III king at Sparta.		*c.* 236 Dedications by Attalus I using sculptors of the First Pergamene School. Apollonius of Perge *flor.*

	Sicily, South Italy, Carthage	Greece and Macedonia	Aegean, Egypt, Cyrene, Asia	Literature, Philosophy, Science, Art
		234 May. Lydiades' first generalship. Attempted expedition against Sparta. (?)Deaths of Ptolemy of Epirus and of Olympias. 233 May. Aratus' seventh generalship. Battle of Phylacia; Bithys defeats Aratus. Aratus attacks Athens up to the Academy. (?) Demetrius invades Boeotia. Collapse of the Epirote royal house: Deidamia murdered. 232 May. Lydiades' second generalship. Arcanania independent of Epirus. 231 May. Aratus' eighth generalship. Demetrius occupied against the Dardanians. Autumn. The Illyrian Ardiaei relieve Medeon, besieged by Aetolians. Death of Agron, king of the Ardiaei.		*c.* 232 Death of Cleanthes (*c.* 331–*c.* 232): succeeded by Chrysippus as head of the Stoa.
230		230 May. Lydiades' third generalship. Illyrian privateering: seizure of Phoenice. Achaeans and Aetolians send help to Epirus against the Illyrians. Epirotes ally themselves with Teuta.	*c.* 230 Ziaelas killed by Galatians.	

229 Corcyra appeals to Achaea and Aetolia.
Battle of Paxos: death of Margus.
229/8 First Illyrian War.
Lydiades tries to bring Argos into the Achaean League.
Death of Demetrius II.
Thessaly revolts from Macedonia: Aetolians invade Thessaly.
Antigonus III Doson succeeds Demetrius: he recovers Thessaliotis, Hestiaeotis and Perrhaebia; Aetolians retain Achaea Phthiotis.
Boeotia and Phocis allied to Achaea.
May. Aratus' ninth generalship.
Argos, Hermione, Phlius and Aegina join Achaean League.
Sparta acquires Tegea, Mantinea, Orchomenus and Caphyae from Aetolia.
Cleomenes takes the Athenaeum.
Aratus attacks Tegea and Orchomenus.
Achaea declares war on Sparta.
Athens declares her independence: negotiations with Diogenes.
228 Aratus seizes Caphyae.
May. Aristomachus general.
Summer. Athens finally free.
c. 228 Doson takes Opuntian Locris from Boeotia.

228 Attalus' victory over Hierax at Lake Coloe; further victory on R. Harpasus.

228 Spring. Romans admitted to Isthmian games.

	Sicily, South Italy, Carthage	Greece and Macedonia	Aegean, Egypt, Cyrene, Asia	Literature, Philosophy, Science, Art
		227 Mutiny at Pella. Antigonus now takes royal title. May. Aratus' tenth generalship. Battle of Mt Lycaeum. Aratus takes Mantinea. Battle of Ladoceia: death of Lydiades. Hierax killed by the Gauls of Tylis. Cleomenes captures Alea and Heraea. Cleomenes' *coup* at Sparta: social reforms carried.	227 Carian expedition of Antigonus Doson.	
		227/6 Megalopolitan embassy to Pella.	227/6 Earthquake seriously damages Rhodes.	
		226 Jan./Feb. Achaean success at Orchomenus. May. Hyperbatas general. Cleomenes takes Mantinea and invades north-west Achaea. Autumn. Battle of Hecatombaeum.	*c.* 227/5 Doson makes treaties with Eleutherna and Hierapytna.	
		Cleomenes approaches the Achaean League.	226/5 Death of Seleucus II: Seleucus III succeeds. 226–223 Attalus master of western Asia Minor.	
225		225 May. Timoxenus general. Conference between Cleomenes and the Achaeans breaks down. Cleomenes takes Pellene, Pheneus, Argos, Cleonae, Phlius, Hermione, Troezen, Epidaurus, Corinth. Aratus *strategos autokrator*. Achaean embassy to Antigonus Doson.		*c.* 225 Rhianus *flor.*

225/4 Aratus besieged in Sicyon.
224 Achaean alliance with Macedonia.
Doson comes south.
May. Aratus' eleventh generalship.
Argos abandons Cleomenes.
Antigonus enters the Peloponnese and takes Aegytis and Belbinatis.
Sept. Antigonus appointed *hegemon* of the allied forces.
224/3 Foundation of the Hellenic Symmachy.
223 Cleomenes attacks Megalopolis.
Antigonus takes Tegea, Orchomenus, Mantinea, Heraea and Telphusa.
Cleomenes takes Megalopolis.

223 Death of Seleucus III.
Accession of Antiochus III.
Molon put in charge of the eastern satrapies.
223/2 (?) Seleucid troops under Achaeus drive Attalus back to Pergamum.

222 Cleomenes invades the Argolid.
May. Aratus' twelfth generalship.
July. Battle of Sellasia.
Cleomenes flees to Egypt.
Antigonus marches north to meet the Illyrians.
222/1 Philip in the Peloponnese.

222 Revolt of Molon.

221 May. Timoxenus general.
c. July. Death of Antigonus: accession of Philip V.
Dorimachus in Messenia.
Autumn. Aetolian aggression at Clarium, in Epirus and on the high seas.
221/20 Winter. Aetolian inroads into Messenia.

221 Feb. Death of Ptolemy III: accession of Ptolemy IV.
Molon defeated and commits suicide.

	Sicily, South Italy, Carthage	Greece and Macedonia	Aegean, Egypt, Cyrene, Asia	Literature, Philosophy, Science, Art
220		220 May. Aratus' thirteenth generalship. Battle of Caphyae. Demetrius of Pharos sails south of Lissus. Sack of Cynaetha. Philip at Corinth. War declared by the Symmachy on Aetolia. 220–217 Social War. 220/19 Philip allied to Scerdilaidas. Spartan alliance with Aetolia. Second Illyrian War: Rome against Demetrius of Pharos.	220 War of Rhodes and Prusias against Byzantium over tolls. War of Cnossus and Gortyn against Lyttus. Troops sent by the Symmachy to help Lyttus. Autumn. Achaeus proclaimed king in Phrygia: rapprochement with Attalus. 220–213 Usurpation of Achaeus.	*c.* 220 Euphorion of Chalcis *flor.* Starting point for the main theme of Polybius' *Histories.*
		219 Spring. Lycurgus attacks the Argolid and seizes the Athenaeum. Summer. Philip in Epirus and Acarnania. Aetolians raid Aegeira, Dium and Dodona. Demetrius of Pharos joins Philip. Philip at Larissa. 219/18 Winter. Philip's winter expedition: Psophis, southern Elis and Triphylia subdued.	219 Fourth Syrian War (219–217) begins: Antiochus III against Ptolemy IV. Antiochus takes Seleuceia-in-Pieria. Theodotus deserts to Antiochus, bringing Ptolemais and Tyre. Death of Cleomenes in Egypt. 219/18 Four months truce between Antiochus and Ptolemy.	
	218–202 Second Punic War.	218 May. Eperatus general. Campaign in north Elis. Financial agreement between Philip and the Achaeans. Philip's naval policy. Apelles at Chalcis. Summer. Philip attacks Cephallenia. Philip invades Aetolia and sacks Thermum.	218 Attalus seizes the Greek cities of northern Ionia, Aeolis and Troas and Mysia to the Macestus, breaking with Achaeus. Antiochus advances south in Coele-Syria.	

	217 June. Battle of Lake Trasimene.	Aetolians attack Messenia and Thessaly. Megaleas condemned. Autumn. Philip in Phocis. Execution of the Apelles group. 218/17 Elean invasion of western Achaea. 217 Summer. Philip takes Bylazora and Phthiotic Thebes. Macedonian preparations against Scerdilaidas. July. Nemea. News of Trasimene. Sept. Peace of Naupactus. Philip's first letter to Larissa on filling the citizen-body.	218/17 Antiochus winters in Ptolemais. 217 June. Battle of Raphia. Ptolemy recovers Coele-Syria: expedition into Seleucid territory. Peace between Ptolemy IV and Antiochus III.	217 Nov. 15. Synod at Memphis (Pithom stele).

BIBLIOGRAPHY

ABBREVIATIONS

For abbreviations of papyrological publications, etc., see Bibliography F(b)

A Arch. Syr. *Annales archéologiques syriennes* (Damascus)

Abh. Akad. Berlin *Abhandlungen der preussischen Akademie der Wissenschaften, Berlin*, phil.-hist. Klasse (later '*der deutschen Akademie der Wissenschaften zu Berlin*, Klasse für Sprache, Literatur und Kunst' or 'Klasse für Philosophie, Geschichte etc.')

Abh. Akad. Mainz *Abhandlungen der Akademie der Wissenschaften und der Literatur, Mainz*, geistes- und sozialwissenschaftliche Klasse

Abh. Sächs. Akad. *Abhandlungen der sächsischen Akademie der Wissenschaften in Leipzig*, phil.-hist. Klasse

Act. ant. *Acta antiqua academiae scientiarum Hungaricae*

Actes Besançon *Actes du colloque sur l'esclavage* (*Besançon*), 1971: Paris, 1972; 1973: Paris, 1976

Actes VII congrès épig. 1977 *Actes du VIIe congrès international d'épigraphie grecque et latine, Constantza 9–15 Sept. 1977.* Bucharest–Paris, 1979

Actes X congr. intern. papyrolog. *Actes du Xe congrès international de papyrologues, Varsovie-Cracovie, 1961*, sous la rédaction de J. Wolski (Académie polonaise de Sciences, Comité des sciences de la culture antique). Warsaw, 1964

Actes XV congr. intern. papyrolog. *Actes du XVe congrès international de papyrologie* (*Pap. Brux.* 16–19), ed. J. Bingen and G. Nachtergael. 4 vols. Brussels, 1978–9

AHDO *Archives d'histoire du droit oriental*

AHR *American Historical Review*

AJAH *American Journal of Ancient History*

AJArch. *American Journal of Archaeology*

AJPhil. *American Journal of Philology*

Ancient Macedonia *Ancient Macedonia*, ed. B. Laourdas, C. Makaronas and others. 3 vols. Thessalonica, 1970, 1977 and 1983

Anc. Soc. *Ancient Society*

Annali di Pisa *Annali della scuola normale superiore de Pisa.* Classe di lettere e filosofia

Ann. Serv. Ant. Égypte *Annales du Service des Antiquités de l'Égypte*

Annuario *Annuario della regia scuola archeologica di Atene e delle missioni italiane in oriente*

ANRW *Aufstieg und Niedergang der römischen Welt: Geschichte und Kultur Roms im Spiegel der neueren Forschung*, ed. H. Temporini and W. Haase. Berlin-New York, 1972–

ANSMN *American Numismatic Society: Museum Notes*

ANSNNM *American Numismatic Society, Numismatic Notes and Monographs*

Ant. class. *L'Antiquité classique*

Antike, Die See *Neue Jahrbücher*

Arch. Anz. *Archäologischer Anzeiger* (supplement to *JDAI*)

Arch. Pap. *Archiv für Papyrusforschung*

Ath. Mitt. *Mitteilungen des Deutschen Archäologischen Instituts, Athenische Abteilung*

Atti Acc. Torino *Atti dell'Accademia delle Scienze di Torino*

Austin M. M. Austin, *The Hellenistic World from Alexander to the Roman Conquest: A Selection of Ancient Sources in Translation*. Cambridge, 1981

BAR *British Archaeological Reports* (Oxford)

BASP *Bulletin of the American Society of Papyrologists*

BCH *Bulletin de correspondance hellénique*

BICS *Bulletin of the Institute of Classical Studies* (London)

BIFAO *Bulletin de l'Institut français d'archéologie orientale*

BM Inventory no., unpublished cuneiform inscriptions in the British Museum

BSA *Annual of the British School at Athens*

BSAAlex. *Bulletin de la société archéologique d'Alexandrie*

Bull. épig. *Bulletin épigraphique* (by L. & J. Robert in *Rev. Ét. Gr.*)

Bull. Hist. Med. *Bulletin of the History of Medicine*

CAH *The Cambridge Ancient History*

Choix F. Durrbach, *Choix d'inscriptions de Délos avec traduction et commentaire* I.1–2. Paris, 1921–3

Chron. d'Égypte *Chronique d'Égypte*

C. Ord Ptol. See Bibliography: F8

Corinth *Corinth*. Results of excavations conducted by the American School of Classical Studies at Athens. Vols. by various authors, 1929–

CPhil. *Classical Philology*

CQ *Classical Quarterly*

CR *Classical Review*

CRAcad. Inscr. *Comptes rendus de l'Académie des inscriptions et belles lettres*

CSCA *California Studies in Classical Antiquity*

CSDIR *Centro studi e documentazione sull'Italia Romana, Atti* (Milan-Varese)

CSSH *Comparative Studies in Society and History*

Das Ptol. Aegypten *Das Ptolemäische Aegypten. Akten des internationalen Symposions 27–29 September 1976 in Berlin*, ed. H. Maehler and V. M. Strocka. Mainz, 1978

Délos *Exploration archéologique de Délos*. Vols. by various authors. 1902–

DHA *Dialogues d'histoire ancienne* (Paris)

Didyma T. Wiegand and others, *Didyma*. I (Buildings): Berlin, 1941; II (Inscriptions, by A. Rehm): Berlin, 1958

Edson Studies *Ancient Macedonian Studies in Honor of Charles F. Edson*, ed. H. Dell. Thessalonica, 1981

EHR *Economic History Review*

Entretiens Hardt *Entretiens sur l'antiquité classique*. Fondation Hardt. Vandoeuvres-Geneva

ESAR *Economic Survey of Ancient Rome*, ed. T. Frank. 6 vols. Baltimore, 1933–40 (reprint New York, 1975)

Fairman Studies *Glimpses of Ancient Egypt. Studies in Honour of H. W. Fairman*, ed. J. Ruffle, G. A. Gaballa and K. A. Kitchen. Warminster, 1979

FD *Fouilles de Delphes*. Vol III: Inscriptions, ed. G. Colin, E. Bourguet, G. Daux and A. Salac. Paris, 1909–

FGrH F. Jacoby, *Fragmente der griechischen Historiker*. 3 parts in 15 vols. (Part 1, ed. 2). Berlin-Leiden, 1923–58

FHG C. Th. Müller, *Fragmenta historicorum graecorum*. 5 vols. Paris, 1841–70

GDI *Sammlung der griechischen Dialekt-Inschriften*, ed. H Collitz and F. Bechtel. Göttingen, 1884–1915

Gött. Anz. *Göttingische gelehrte Anzeigen*

GRBS *Greek Roman and Byzantine Studies*

Harv. Theol. Rev. *Harvard Theological Review*

Hesp. *Hesperia. Journal of the American School of Classical Studies at Athens*

Holleaux, *Études* M. Holleaux, *Études d'épigraphie et d'histoire grecques*, ed. L. Robert. 6 vols. Paris, 1938–68

HSCP *Harvard Studies in Classical Philology*

IBM *The Collection of Ancient Greek Inscriptions in the British Museum*. London, 1874–1916

IC *Inscriptiones Creticae*, ed. M. Guarducci. 4 vols. Rome, 1935–50

IEJ *Israel Exploration Journal*

IG *Inscriptiones Graecae*

IG^2 *Inscriptiones Graecae*, editio minor

IGB G. Mihailov, *Inscriptiones Graecae in Bulgaria repertae*. Sofia. I^2 (1970), II (1958), III.1 (1961), III.2 (1964), IV (1966)

IGCH O. Mørkholm, C. M. Kraay and M. Thompson, *An Inventory of Greek Coin Hoards*. New York, 1973

IGLS *Inscriptions grecques et latines de la Syrie*, ed. L. Jalabert, R. Mouterde and J. P. Rey-Coquais. Paris, 1929–

ILS *Inscriptiones latinae selectae*, ed. H. Dessau

I. Magnesia *Die Inschriften von Magnesia-am-Mäander*, ed. O. Kern. Berlin, 1900

Insc. Délos *Inscriptions de Délos:* nos. 1–88, ed. A. Plassart, Paris, 1950; nos. 290–371, 372–509, ed. F. Durrbach, Paris, 1926 and 1929; nos. 1400–96, ed. F. Durrbach and P. Roussel, Paris, 1935; nos. 1497–2879 (2 parts), ed. P. Roussel and M. Launey, Paris, 1937

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ISE L. Moretti, *Iscrizioni storiche ellenistiche*. 2 vols. Florence, 1967 and 1975

Istanb. Forsch. *Istanbuler Forschungen*

Istanb. Mitt. *Mitteilungen des deutschen archäologischen Instituts, Istanbuler Abteilung*
JCS *Journal of Cuneiform Studies*
JDAI *Jahrbuch des (kaiserlichen) Deutschen Archäologischen Instituts*
JEA *Journal of Egyptian Archaeology*
JHS *Journal of Hellenic Studies*
JJP *Journal of Juristic Papyrology*
Journ. asiatique *Journal asiatique*
Journ. Econ. Bus. Hist. *Journal of Economic and Business History*
Journ. Sav. *Journal des savants*
JRS *Journal of Roman Studies*
Kuml *Kuml. Årbog for Jysk Arkaeologisk Selskab* (Århus)
Lindos *Lindos: Fouilles de l'Acropole, 1902–14.* I and II, by Ch. Blinkenberg. *Le Sanctuaire d'Athéna Lindia et l'architecture lindienne*, with catalogue of V. Poulsen; III, by E. Dyggve and others. Berlin-Copenhagen, 1931–60
MAAR *Memoirs of the American Academy in Rome*
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Mél. USJ *Mélanges de l'Université St Joseph, Beyrouth*
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Mus. Helv. *Museum Helveticum*
[*Neue*] *Jahrbücher* (1) [*Neue*] *Jahrbücher für Philologie und Pädagogik* (1826–97) (2) *Neue Jahrbücher für das Klassische Altertum und für Pädagogik* (1898–1925)

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Num. Chron. *Numismatic Chronicle*

Num. Stud. *American Numismatic Society: Numismatic Studies*

OGIS *Orientis graeci inscriptiones selectae*, ed. W. Dittenberger. 2 vols. Leipzig, 1903

Op. Ath. *Opuscula Atheniensia.* Skrifter utgivna av Svenska Institutet i Athen

Philol. *Philologus*

PIR *Prosopographia imperii Romani saec. I, II, III*, ed. E. Klebs, H. Dessau, P. von Rohden. 3 vols. Berlin, 1897–8
New edition: ed. E. Groag, A. Stein, L. Petersen. Berlin-Leipzig, 1933–

Pol. Sci. Quart. *Political Science Quarterly*

PP *La parola del passato*

Proc. Brit. Acad. *Proceedings of the British Academy*

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PW Pauly, Wissowa and others, *Real-Encyclopädie der classischen Altertums-Wissenschaft*

Quad. Tic. *Quaderni ticinesi di numismatica e antichità classiche* (Lugano)

RBPhil. *Revue belge de philologie et d'histoire*

RC C. B. Welles, *Royal Correspondence in the Hellenistic Period: A Study in Greek Epigraphy.* New Haven, Conn., 1934

Rend. Ist. Lomb. *Rendiconti del Istituto Lombardo di scienze e lettere*

Rend. Linc. *Rendiconti dell'Accademia dei Lincei*

Rev. Bibl. *Revue biblique*

Rev. Ét. Anc. *Revue des études anciennes*

Rev. Ét. Gr. *Revue des études grecques*

Rev. Hist. *Revue historique*

Rev. Num. *Revue numismatique*
Rev. Phil. *Revue de philologie*
RGVV *Religionsgeschichtliche Versuche und Vorarbeiten*
Rh. Mus. *Rheinisches Museum für Philologie*
RIDA *Revue internationale des droits de l'Antiquité*
Riv. Fil. *Rivista di filologia e d'istruzione classica*
Robert, *Hellenica* L. Robert, *Hellenica. Recueil d'épigraphie, de numismatique et d'antiquités grecques.* 13 vols. Paris, 1940 (I), 1946 (II–III), 1948 (IV–VI), 1949 (VII), 1950 (VIII–IX), 1955 (X), 1960 (XI–XII), 1965 (XIII)
Robert, *OMS* L. Robert, *Opera minora selecta*
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SEG *Supplementum epigraphicum graecum*
SIG W. Dittenberger, *Sylloge inscriptionum graecarum.* 4 vols. Ed. 3. Leipzig, 1915–24
Sitz. Bayer. Akad. *Sitzungsberichte der Bayerischen Akademie der Wissenschaften*, phil.-hist. Abteilung
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SVA *Die Staatsverträge des Altertums* II: *Die Verträge der griechisch-römischen Welt von 700 bis 338 v. Chr.*, ed. H. Bengtson. Ed. 2, 1975; III: *Die Verträge der griechisch-römischen Welt von 338 bis 200 v. Chr.*, ed. H. H. Schmitt. Munich, 1969
SVF H. Diels and W. Kranz, *Fragmente der Vorsokratiker.* 3 vols. Ed. 6. Berlin, 1951–2
TAPA *Transactions of the American Philological Association*
Tod M. N. Tod, *Greek Historical Inscriptions* I, ed. 2, 1946; II, 1948. Oxford
UPZ U. Wilcken, *Urkunden der Ptolemäerzeit.* 2 vols. Berlin-Leipzig, 1922–7 and 1957
VDI *Vestnik drevnej istorii*
Verhandelingen v. d. Kon. Acad. Belgie *Verhandelingen van der Koninklijke Academie voor Wetenschappen Letteren en Schone Kunsten van Belgie*, Klasse de Letteren
Welles Essays *Essays in Honor of C. Bradford Welles* (*American Studies in Papyrology* I). New Haven, 1966
Wilcken, *Grundzüge* and *Chr.* See Wilcken 1912: (F 91)
YCS *Yale Classical Studies*
ZAeS *Zeitschrift für ägyptische Sprache und Altertumskunde*
ZPE *Zeitschrift für Papyrologie und Epigraphik*
ZSS *Zeitschrift der Savigny-Stiftung für Rechtsgeschichte*, Romanistische Abteilung

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